THE FORAMEN MAGNUM AND ITS CONTENTS: A MAGNETIC RESONANCE IMAGING STUDY OF THE NORMAL SPATIAL RELATIONSHIPS.

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A dissertation submitted to the Faculty of Medicine of the University of Cape Town in fulfilment of the requirements for the degree of Master of Science in Medicine [MSc Med] in Anatomy.

Cape Town
199~~2~~4

LIST OF CORRECTIONS

1. Figure 3: The figure was further explained in an additional paragraph in the text. The Y-axis is present and represents a relative index of the vertical position of the tonsil in relation to the foramen magnum. The X-axis represents age. Specific reference was made to the Y-axis in the legend. **(Page 8)**

2. Typographical error corrected on page 4: Quadrigeminal. **(Page 4)**

3. Fig 6: Section 1.5.1 changed to 1.4.1. This error was corrected in the original draft, but an uncorrected copy unfortunately reached this specific examiner. **(Page 19)**

4. The abbreviations of references were left unaltered. The list of references was prepared according to the style of the Radiological Society of North America. An explanation to this effect (Section 2.4) was added to the chapter on Materials and Methods. **(Page 23)**

5. References 15 and 16 were completed by adding outstanding page numbers. 15: 281-289; 16: 615-633. **(Page 54)**

6. Reference 25 corrected by adding an "r" to Tomogr **(Page 55)**

7. Reference 6 corrected by completing "Radiology" and erasing "1" from the volume number ie volume 183. **(Page 54)**

DECLARATION

I, JAN WILLEM LOTZ, declare that this dissertation is my own work. It is submitted for the degree of Master of Science in Medicine [MSc(Med)] in the University of Cape Town, and has not been presented for any degree of another university.

Signed :

Day of **19**

The work presented in this dissertation was carried out in the City Park MRI Centre, City Park Hospital, Cape Town, under guidance of the Department of Anatomy, Faculty of Medicine, University of Cape Town.

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ABSTRACT

The well-known neurological disturbances associated with caudal displacement of the cerebellar tonsils through the foramen magnum (Chiari malformation) have lead to many radiological studies of the region. With MRI, routine sagittal and parasagittal views of the craniovertebral junction have shown that the position of the cerebellar tonsils is variable, and in many otherwise healthy individuals, the inferior tonsillar margins lie within the foramen magnum itself. In some cases, this topography is associated with little signal from the surrounding cerebro-spinal fluid (CSF), indicating reduction of the cerebellomedullary cistern and, therefore, crowding of neural structures within the confines of the foramen.

The objective of this study has been to examine the spatial relationship between the contents of the foramen magnum ie. the medulla and cerebellar tonsils, using a normal sample comprising 120 volunteers. Instead of the conventional measurements of distance, a ratio, the **Foramen Magnum Index (FMI)**, has been determined, derived from the relative surface areas (pixels) of neural parenchyma and CSF, over axially and sagittaly-defined boundaries of the foramen. The **FMI**, with a 95th centile of 0.77, exhibits appropriate statistical correlation with tonsillar position below the level of the foramen, and is therefore considered specific. As a quantitative means of assessing the cerebellomedullary cistern, the **FMI** also identifies certain subjects whose tonsils are at the foramen, in whom the cistern is small with resultant neural crowding.

ACKNOWLEDGEMENTS

This thesis could not have been entertained without the help of various people whose generosity I have great pleasure in acknowledging:

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CHAPTER 1

1. INTRODUCTION

1.1 ANATOMY

1.1.1 CRANIOVERTEBRAL JUNCTION

The craniovertebral junction, being a term of primarily neurosurgical and radiologic usage, is an area without defined boundaries and includes the bones of the posterior skull base and upper two cervical vertebra.

1.1.2 THE FORAMEN MAGNUM

The foramen magnum is situated in the median region of the posterior part of the skull base, bounded by the basilar part of the occipital bone in front, the lateral part on each side, and a small portion of the squamous part behind. Anteriorly, basiocciput and basisphenoid form a sloping surface, the clivus, which is gently concave from side to side, antero-inferior to the pons and medulla oblongata. The rostral clivus is separated on each side from the petrous part of the temporal bone by the petro-occipital fissure; caudally, it terminates as the sharp, anterior lip of the foramen, which then becomes broadened and roughened laterally to form the medial aspects of the occipital condyles. Dorsal to the condylar masses, the posterior margin again becomes sharpened, commensurate with the thickness of the posterior occipital bone. The interior, ventral parts of the foraminal rim give attachment to the membrana tectoria, cruciate ligaments and joint capsules, these structures being blended to one another, as well as to the overlying dura. The sharp edge of the foramen itself receives the apical ligament of the dens, a structure lying within a fat-filled space of no precise anatomic nomenclature, bounded externally by the anterior fibres of the atlanto-occipital membrane **(Fig 1a)**. The posterior atlanto-occipital membrane fibres, whose anterior free margins are formed by the intrusion of the vertebral arteries, find their attachment to the sharp posterior or dorsal aspect of the foramen. The dura is lightly fixed to the posterior ligament, providing only a potential space **(Fig 1a)**. Immediately adjacent to the rim, the bone is punctured by emissary vessels.

The foramen magnum is ovoid, narrower in front and sometimes exhibiting perceptible anteromedial encroachment by the occipital condyles; in the adult its average measurements are 34 mm in the antero-posterior diameter and 29 mm in the transverse.[1] Its narrow ventral part transmits the medulla, vertebral arteries (together with their sympathetic plexuses), spinal roots of the accessory nerves, and the most proximal parts of the dentate ligaments.

1.1.3 THE CEREBELLOMEDULLARY CISTERN

The craniovertebral subarachnoid space, within which these structures are contained, comprises the cerebellomedullary cistern (or cisterna magna) whose historical and present definitions have been reviewed by Liliequist.[2]

The boundaries are complex and to a certain extent, arbitrary, commencing rostrally at the level of the pontomedullary junction and cerebellar incisura, and becoming continuous below with the spinal subarachnoid space at the level of the arch of C1 **(Fig 1a;1b)**. The foramen magnum may be considered to divide the intracranial and spinal parts of the cistern, and an imaginary line connecting the anterior and posterior (sagittal) margins of the aperture usually crosses the caudal medulla slightly obliquely. The intracranial cerebellomedullary cistern has a smaller ventral part containing the medulla and vertebral vessels, and a larger dorsal part enclosing as well as intervening between the tonsils. The dorsal part is limited superiorly by the attachment of arachnoid membrane to the inferior surfaces of the cerebellar hemispheres, and inferiorly by the occipital squame and its free margin.

Its variable morphology, described in detail by Liliequist, is principally determined by the size, shape and position of the tonsils, diminishing progressively in volume as these structures encroach on the foramen **(Fig 2)**. An extrinsic factor of particular significance influencing cisternal morphology, is that of basioccipital clivus angulation and length.[1] Below the foramen magnum, the spinal part of the cistern is usually widest dorsally, constricting sharply at the level of the posterior arch of C1. The rostrocaudal extent of the space is influenced by condylar height and head position, but is of the order 15 mm in the mid- sagittal plane **(Fig 1a; 1b)**

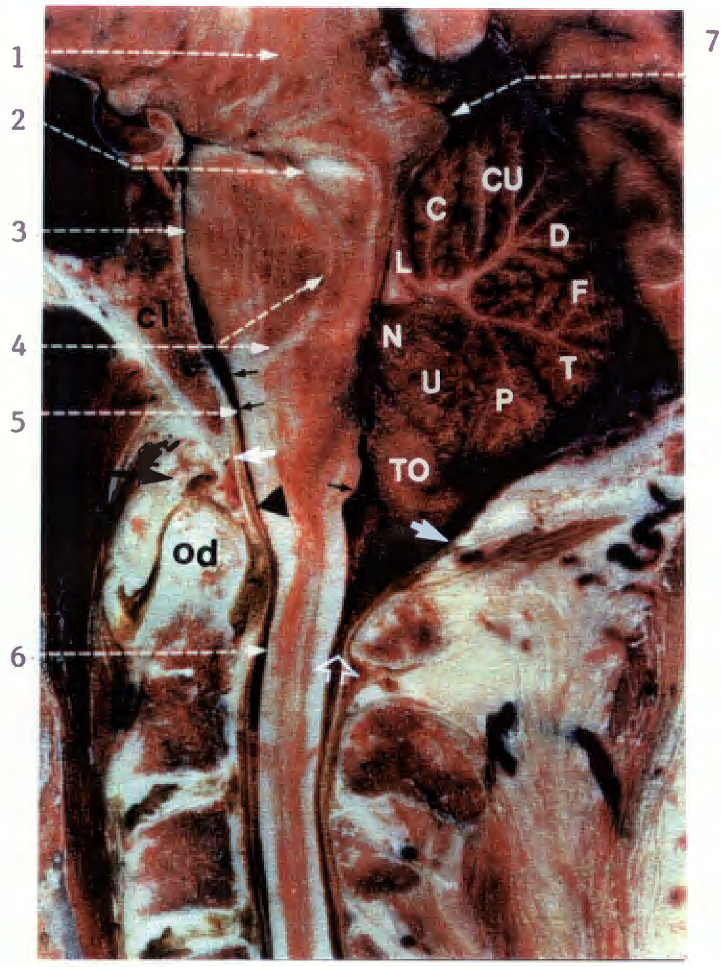


Figure 1a
Sagittal anatomic section through the brainstem and cerebellar vermis to show the position of the cerebellar tonsil in the inferior aspect of the cerebellomedullary cistern.

1	thalamus	D	declive
2	decussation of peduncles	F	folium
3	pons	T	tuber
4	medial lemniscus	P	pyramis
5	medulla	U	uvula
6	spinal cord	TO	tonsil
7	quadrigeminal plate	N	nodulus
L	lingula	od	odontoid
C	central lobule	cl	clivus
CU	culmen		

Anterior and posterior rim of foramen magnum, white arrows; Areolar tissue above dens, black arrow; membrana tectoria, black arrowhead; cerebellomedullary cistern, small black arrows; inferior constriction, open arrow.

Figure 1b
Sagittal midline section showing landmarks and extent of the cerebellomedullary cistern.

Clivus, cl; tonsil, to; anterior and posterior rim of foramen magnum, white arrows; apical "fat pad", black arrow; cerebellomedullary cistern, small black arrows; inferior constriction, open arrow.

With MRI, cortical bone, lacking sufficient hydrogen protons, appears as a black signal void. The margins of the foramen magnum are identified in sagittal T1 images by the morphology of the clivus and occipital squama, and their internal fat content which is hyperintense. The precise cortical margins are also usually visible against the lesser hypointensity of the cerebrospinal fluid, whilst the areolar tissue surrounding the apical ligament usually provides a consistent landmark (Fig 1b). The neural parenchyma of the tonsils and medulla has an intermediate intensity signal which is only slightly blurred by the slice width.[3 4]

1.2 DEVELOPMENT

As is well known, the developing chondrocranium, from which the skull base is formed, features the process of ossification even before the phase of cartilaginous growth is complete.[5] At birth, the occiput comprises three ossified portions (basi-, ex- and supra-occipital) whose neuraxial surrounds constitute the foramen magnum. At this stage, the basilar and condylar components, separated by synchondroses, provide a complete bony rim which makes up five sixths of the foramen. The narrow posterior component is cartilaginous, sometimes possessing its own distinct ossification centre (Kerckring's centre).

The anterior synchondroses begin to diminish early, at about 18 months, disappearing by the fourth year. Significantly, the posterior synchondrosis is only obliterated by the 7th year,[1] by which time its contribution to the circumference of the foramen magnum has come to equal that of the other three components. Compared with that of mesenchymal osseous calvarium, the effect of the developing brain on growth of the cartilaginous neurocranium is said to be small. The possession by these bones of their own growth dynamics renders the skull base stable and predictable, with development which apparently parallels that of the body, rather than the brain.[1]

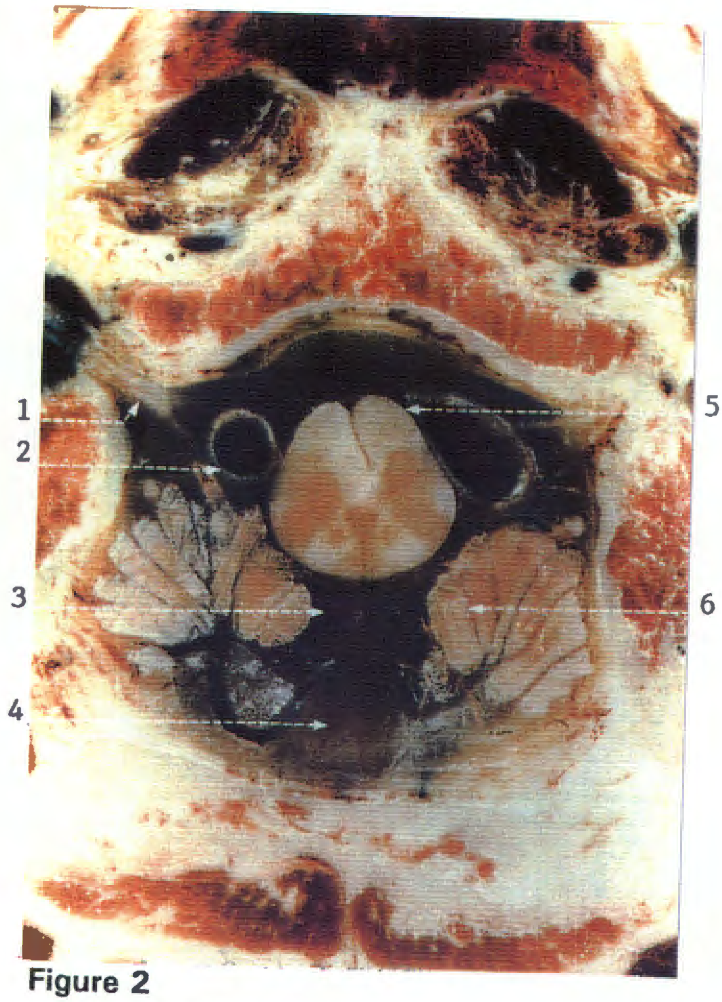


Figure 2
Axial anatomic section through the cerebellomedullary cistern above the foramen magnum. The position of the tonsils relative to the brainstem in the inferior aspect of the cistern is evident.

1 cranial nerve XII in hypoglossal canal
2 vertebral artery
3 vallecula
4 cisterna magna
5 pyramid
6 cerebellar tonsil

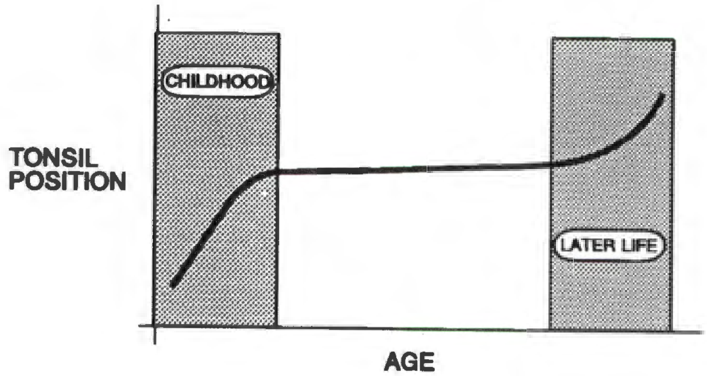


Figure 3
Age/position relationship curve. The Y-axis is a relative index of the vertical position of the tonsil in relation to the foramen magnum. (Reproduced with permission Mikulis et al.)

Standard anatomical and embryological texts do not deal with the specific relationships or dynamics of the hindbrain and posterior fossa, and it is only with the advent of MR that some of these aspects have come to be examined in the general population. In an apparently novel observation, the position of the cerebellar tonsils vis-a-vis the foramen magnum has recently been shown to be a function of age, including their normal protrusion through the foramen in early life (Fig 3).[6] The Y-axis in this illustration is a relative index of the vertical position of the tonsil in relation to the foramen magnum. In Early childhood the tonsil generally extends to or below the foramen magnum. Thereafter there is a gradual receding of the tonsils with age, levelling off in early adulthood. Later in life a secondary recession occurs.

1.3 HISTORICAL SURVEY OF RADIOLOGICAL INVESTIGATION OF THE SKULL BASE

1.3.1 SKULL RADIOGRAPHS

Roentgenograms of the skull were obtained at an early stage of development of radiology, despite exposure times as long as 30 minutes, with intervals of 1 minute direct exposure alternating with 1 minute for cooling of the tube. In 1901 however Pfahler, using an exposure time of 4 minutes and a tube distance of 18 inches obtained a view that "showed good detail of all structures..."[7] During the first decade of the twentieth century, men such as A Schuller achieved adequate projections for the demonstration of detailed skull anatomy, together with the establishment of normal appearances.[8 9]

The foramen magnum is well shown in the Chamberlain-Towne projection. In lateral projections, the anterior and posterior margins of the foramen magnum can be visualized, and the anterior rim is easily recognized as the inferior tip of the clivus. The posterior rim of the foramen may be indistinct, but its location can often be estimated by its position relative to the posterior arch of the first cervical vertebra. In the axial projection the foramen magnum is obscured and is often confused with the margins of the upper cervical canal.

During the 1940s, a number of measurements were developed for the assessment of normal and abnormal configuration of the skull base and craniovertebral junction. Alignments of particular significance include those joining the posterior end of the hard palate to the posterior lip of the foramen magnum (Chamberlain), and the posterior end of the hard palate to the lowermost point of the occipital squama (McGregor). The digastric line joins the left and right digastric notches and the bimastoid line joins the tips of the left and right mastoid processes. In about fifty percent of normal persons the tip of the odontoid process is at or below Chamberlain's and McGregor's lines. If more than half of the odontoid process is above one of these lines, basilar invagination is assumed. The digastric line normally lies 11mm (+-4mm) above the middle of the atlanto-occipital joints. Basilar invagination is almost certainly present when the atlanto-occipital joint is at or above the digastric line.[10]

The basal angle, obtained by drawing lines from the tuberculum sellae to the anterior lip of the foramen magnum and to the nasofrontal suture on a lateral roentgenogram, is used to define the plane of the clivus in relation to plane of the midline portion of the base of the anterior fossa. This measurement has been used extensively in skull taxonomy.[11]

1.3.2 PNEUMOGRAPHY

Despite the fact that air had been observed in the cranium following fractures, its use as a contrast medium for examination of the intracranial spaces was first established by Walter Dandy in 1919, and is widely considered to have signified the birth of neuroradiology.[12]

Because pneumographic diagnosis was based on the interpretation of standard skull projections, accurate positioning of the head became critical. Accordingly, a skull table was developed by Lysholm in 1931 and represented the first precision apparatus for roentgenography.[13]

1.3.3 POSITIVE CONTRAST VENTRICULOGRAPHY

The first positive contrast medium employed in neuroradiology was an iodized oil introduced for myelography in 1922,[14] and subsequently used by Balado in 1928 for investigation of the ventricular system. The Stockholm school also used lipiodol in the mid 1930's but its non-resorbable, sclerosing nature caused its abandonment. Concurrently, the pneumographic technique was found to give equally good results.

The early 1940's saw the introduction of Pantopaque, a mixture of esters of isomeric iodophenyl undecylenic acid; much less viscous than lipiodil at body temperature, it became the most widely-used contrast medium for investigation of the intracranial cerebrospinal fluid spaces. The search for water-soluble radiographic media for cerebral ventriculography was stimulated by Heimburger et al in 1966.[15] Although the high osmolarity proved to be unsuitable for the sensitive tissues of the CNS [16] [17], metrizamide myelography enabled Bloch et al in 1974 to provide a quantitative definition of the relationship between the cerebellar tonsils and the foramen magnum.[18] The introduction of low-osmolarity, water-soluble contrast material with remarkable reduction in side effects, combined with the advent of CT has set the tone of anatomic delineation, including that of the craniovertebral junction, for the remainder of the decade.

1.3.4 COMPUTED AXIAL TOMOGRAPHY

High resolution computed tomography (HRCT) with bone and soft tissue windows represented the next significant advance in imaging the skull base and craniovertebral junction.[19] Using reconstruction techniques in combination with intrathecal contrast injection, it was possible to establish the exact position of the cerebellar tonsils in relation to the upper cervical cord and medulla.[20] [21] [22]

1.3.5 MAGNETIC RESONANCE IMAGING

The supremacy of MR in neuroimaging is now unquestioned, and even allowing for the signal void of cortical bone, the structures of the posterior fossa and craniovertebral junction are particularly important examples of the advantageous use of the modality.[23] [24] As a direct result, the problem of normal and abnormal cerebellar tonsillar (and brainstem) morphology has received a great deal of scrutiny.[25] [26] [27]

1.4 THE CHIARI MALFORMATIONS

In 1891, H. Chiari described the morbid anatomical features of three forms of infantile cerebellar malformation, providing the basis for the classification which is still associated with his name.[28]

Type I malformation consists of downward displacement of the cerebellar tonsils through the foramen magnum, while the fourth ventricle remains in a relatively normal position. Type II malformation, nearly always associated with myelodysplasia, shows displacement of the vermis and tonsils into the spinal canal, together with caudal displacement of the brainstem and elongation of the fourth ventricle. In Type III malformation, herniation of the cerebellum occurs first through the foramen magnum, then dorsally through a cervical spina bifida, forming a cervical encephalocoele.

1.4.1 CHIARI I MALFORMATION AND THE VERTICAL POSITION OF THE CEREBELLAR TONSILS

Since the Chiari Type I malformation is characteristically asymptomatic before early adulthood, and since many individuals are encountered in whom a degree of tonsillar displacement appears to be an incidental finding, a problem immediately arises with regard to the distinction between normal variant, and malformation. This, simply put, has been the area of controversy for almost 30 years, commencing with the quantitative myelographic studies of Baker [29] and Bloch [18], and continuing into the MR era with those of Aboulezz [26], Barkovich [30] and Mikulis.[6]

In current MRI morphometry, the true level of the cerebellar tonsils below the foramen magnum is estimated. Using a midline sagittal section, a reference line is obtained by joining the anterior rim (point A) with the posterior rim (point B) of the foramen magnum. The length of the line AB also represents the sagittal diameter of the foramen magnum. A second measured line connects A with the lower pole of the tonsils (point C), and the angle Θ between AB and AC is measured. (Fig 4). The shortest distance between the cerebellar tonsils and the foramen magnum is now calculated by the simple calculation

$$x = AC \sin \Theta$$

where x is a perpendicular between C and AB. Values are recorded with positive or negative sign depending on whether or not the cerebellar tonsils had their inferior poles above or below the reference line AB.[26] These studies conclude that in the absence of any other structural abnormality, tonsils lying at or less than 3 mm below, the level of the foramen magnum may still be considered normal, the ectopic position being exceptional. Extension or displacement for more than 5 mm below the foramen magnum (mean 13 mm) is consistent with the diagnosis of Chiari I malformation. In cases where displacement is 3-5mm below the reference line, elongation of the tonsils in association with a narrowed fourth ventricle is diagnostically suggestive.

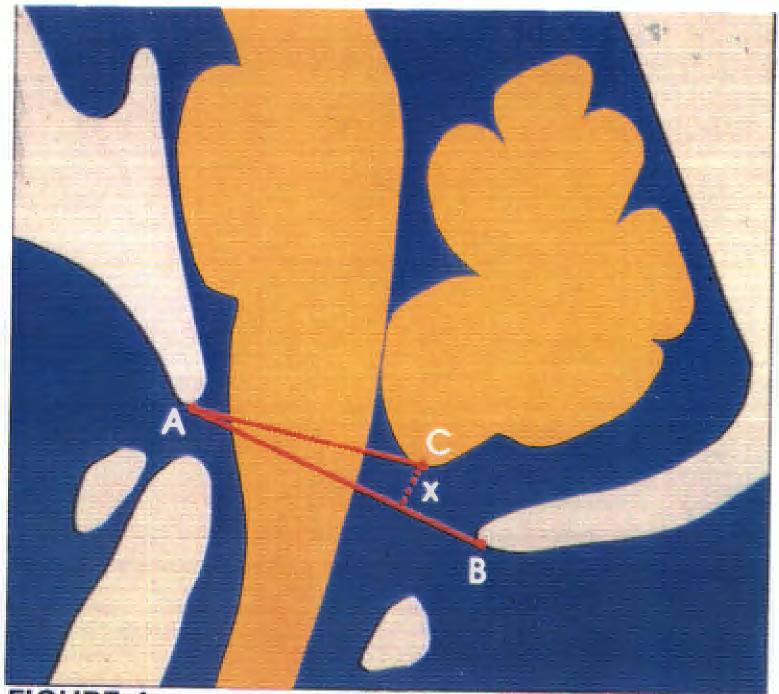


FIGURE 4
Method of determining the distance between cerebellar tonsils and foramen magnum by MR (Aboulezz et al)

1.5 RATIONALE FOR THE STUDY

Compared with the abovementioned studies (where the primary objective has always been to examine the correlation between vertical tonsillar position and symptomatology), observations made in this Unit during routine examination of the posterior fossa and craniovertebral junction, have shown that the cerebellar tonsils may descend to below 5mm of the plane of the foramen magnum and yet be associated with an easily identified cerebrospinal fluid space. In other cases, the tonsils might scarcely reach the level of the foramen magnum, yet the subarachnoid space is obliterated, and the neural structures are in close apposition to one another, suggesting compression or crowding within the bony confines of the aperture.

The natural consequence of this finding was that a correlation might exist between the presence and degree of impaction of neural tissue at the level of the foramen magnum and clinical symptomatology, and that such correlation might be statistically more significant than the relationship of vertical tonsillar level. To test this hypothesis, a quantitative assessment of the normal volumetric relationships between foramen magnum and its contents is necessary. The purpose of this dissertation is therefore to establish a ratio of the relative volumes of neural parenchyma and CSF over an arbitrary but limited area of craniovertebral junction.

CHAPTER 2

2. MATERIAL AND METHODS

2.1 CASE STUDIES

The study included 120 volunteers, equally divided between the sexes, with an age range of 18 to 66 years (Table 1). Individuals were fully informed of the nature of the examination, and consent was obtained to perform a T1 weighted paraxial sequence through the craniovertebral junction. This procedure added 3 minutes 47 seconds to the total scanning time. Only subjects with normal routine scans were included in the project.

2.2 SCANNING PARAMETERS

Because this exposition is primarily morphological, no attempt is made to explain the physical principles of MRI. The study was performed on a 1 Tesla superconducting unit, using a technique routine to clinical practice, ie. multislice spin-echo. All patients were scanned in sagittal and axial planes, using T1-weighted (TR200 milliseconds(ms)/TE15ms) images. Slice thickness was 5mm with an interslice gap of 1mm. Four acquisitions with a field of view (FOV) of 230 and processing on a matrix of 256x256, resulted in a total scanning time of 3 minutes 47 seconds. A coronal topogram (Fig 5) was used to plan a sagittal sequence through the midline structures of pons, medulla and cerebellum.

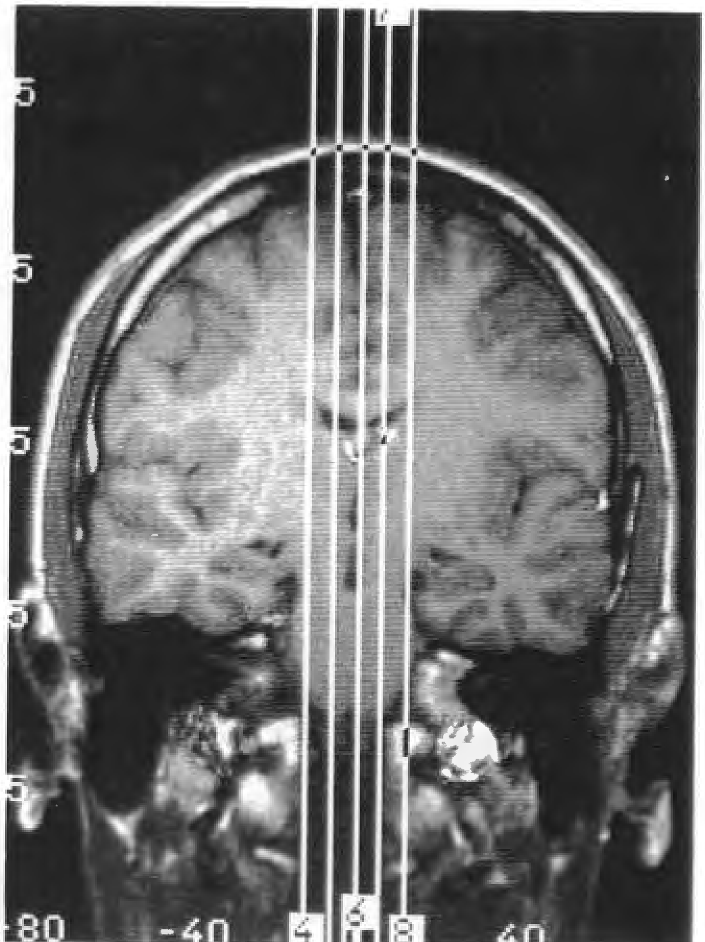


Figure 5
Coronal topogram: vertical lines indicate position of sagittal sections through the craniovertebral junction.

The axial sequence through the foramen magnum was planned on the midline sagittal section using the anatomic reference points described in Section 1.4.1 (Fig 6). The sequence allows 5 axial sections of which the middle slice (section 3) corresponds exactly with the anatomical plane of the foramen magnum (Fig 7).

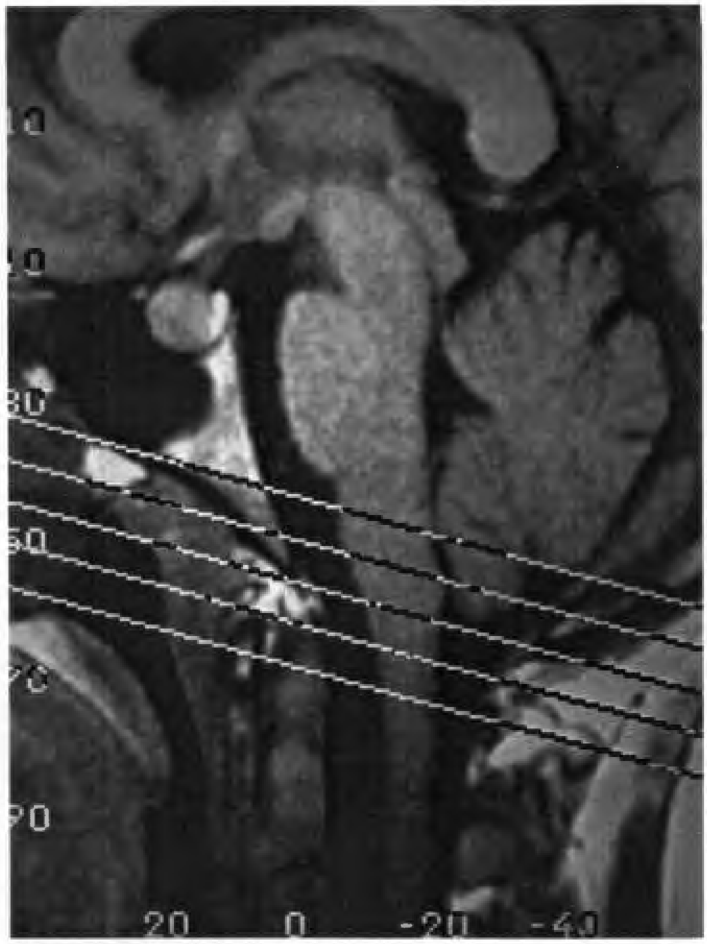


Figure 6
Sagittal midline topogram through craniovertebral junction. Axial sections are orientated according to the anatomical landmarks described in section 1.4.1

A circularly polarized head coil with a diameter of 30cm was used in all cases allowing simultaneous evaluation of the craniovertebral junction, most of the intracranial structures and the upper cervical cord.

In T1-weighted images, the grey scale reveals compact soft tissues such as muscle, brain and liver, as having intermediate signal intensity. Bulk water as occurs in the cerebrospinal fluid spaces, is dark or hypointense, whilst cells and

tissues containing neutral lipids such as adipose tissue, exhibit marked hyperintensity. Tissues having little water (or mobile hydrogen protons) such as bone and tendon may have no signal (signal void) and therefore are pitch black. Water, being a ubiquitous source of protons in biologic tissue, strongly influences their T1 relaxation values, and hence contrast on T1-weighted images. The neuraxis is best visualised on these images as contrast between cerebro-spinal fluid, neural tissue, bone and fat is maximized.

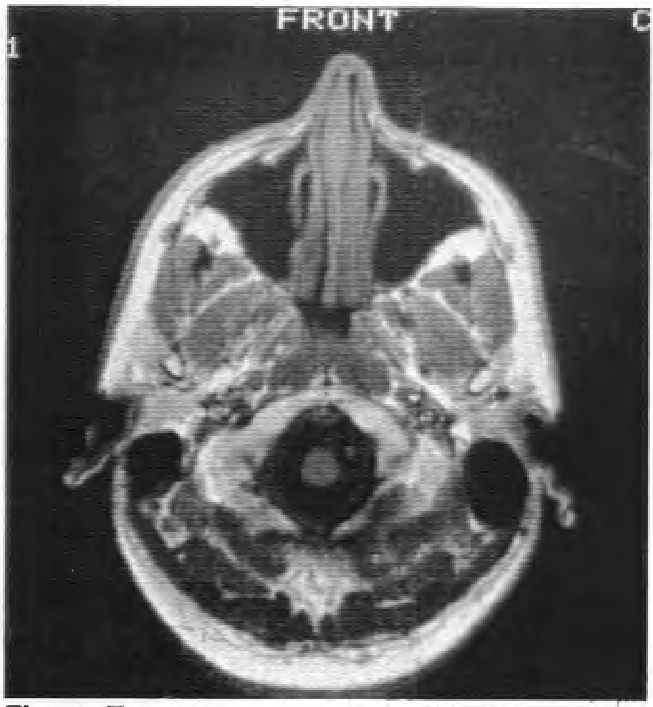


Figure 7
Axial section through the plane of the foramen magnum. The margin of the foramen is delineated by the low intensity (black) signal void of the cortical rim.

The axial section through the foramen magnum shows the relation of neural tissue, CSF space and the bony margin of the foramen magnum is defined by a low intensity cortical margin. Neural tissue within the confines of the foramen is represented by structures with intermediate signal intensity, while CSF spaces project as low intensity areas, consistent with the long relaxation values of water.

2.3 MEASUREMENTS

Evaluation was performed on the 'Statistics' programme of the D2 version of the Magnetom software, which allows measurement by selecting a region of interest (ROI). ROI-types include square, circle, ellipse and free patterns **(Fig 8)**.

Circle: superimposes a circular field over the region of interest which can be contracted or expanded radially.

Ellipse: superimposes an elliptical field over the region of interest. Longitudinal and transverse axes can be selectively expanded or contracted.

Free: superimposes a free ROI. Any desired form, location or size may be drawn with a pen. The starting point is defined by lifting up the pen. After repositioning the pen, free drawing of the contour begins and can be in interrupted arbitrarily by following the same procedure used for starting. By lifting the pen at the start position, after a closed area is drawn, the drawing is ended. A free ROI can be shifted.

Measurements obtained include the following:

Area: This is a mathematical calculation of the area defined under the ROI.

Pixel Count: The number of picture elements (pixels) per millimetre is known for a given matrix size and, therefore, for a defined ROI. Hence the number of pixels for a given ROI can be determined.

Volume: A mathematical calculation of the volume as a function of slice thickness (area x slice thickness).

The surface area and pixel counts of the respective regions are interlinked and provide identical data. Volumetric measurement is a function of slice thickness and does not take contour variations into account. For these reasons, only surface area measurements were applied in the final statistical analyses.

The axial section through the foramen magnum is selected and a ROI introduced over brainstem, right tonsil (if present), left tonsil (if present) and foramen magnum **(Fig 9a;b;c;d)**. The brainstem is usually identified as a circular iso-intense structure surrounded by low intensity CSF. The tonsils are situated postero-laterally and are usually oval in configuration. The foramen magnum is an oval aperture and is defined by a low intensity cortical rim. If any of the above structures do not conform to the fixed ROI configurations, a free ROI is introduced and the outline is drawn in.

The vertical position of the cerebellar tonsil (ton-lv) was measured according to the principles of Aboulezz et al.[26] as summarised in Section 1.4.1 **(Fig 4)**. However, in contrast to the technique of these authors who used only a mid-sagittal slice, the vertical height of the tonsils was measured on two additional parasagittal sections 5mm on either side of the midline. The distance between the lowest position of the tonsil (point C) and the plane of the foramen magnum (line AB) was obtained electronically (Fig 4).

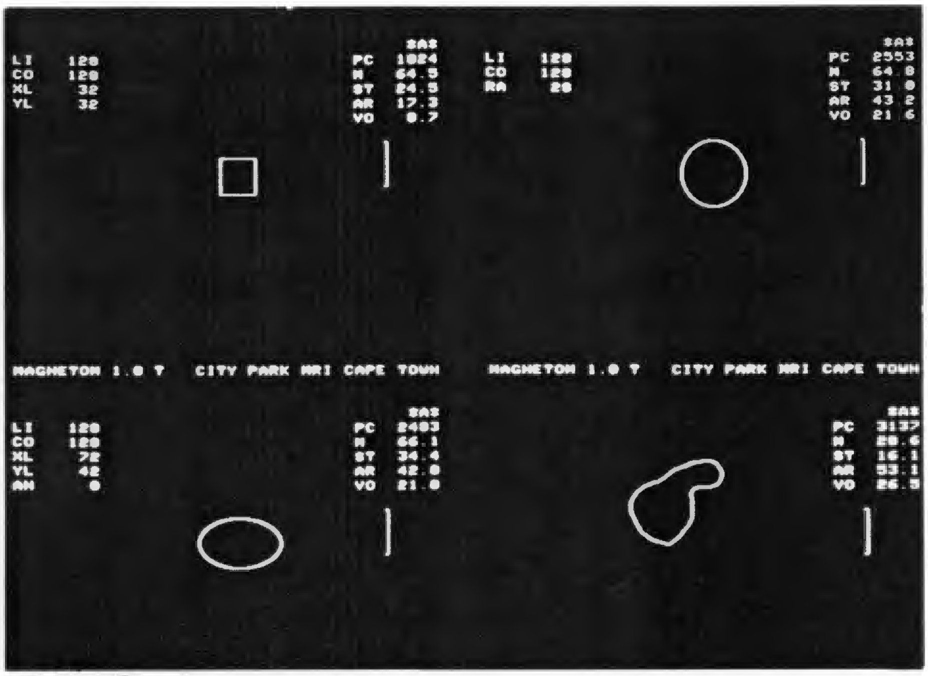


Figure 8
Region of interest (ROI) types. Selection of square, circle, oval and free patterns are possible.

Data were then transferred to a spreadsheet. The area of the cord (area cord) was added to the area of the right tonsil (area right) (if present) and the area of the left tonsil (area left) (if present). The sum of these areas (area sum) was then expressed as a ratio (rat-area) of the area of the foramen magnum (area for) which then constituted the **Foramen Magnum Index (FMI)**.

$$FMI = (\text{Area cord} + \text{area rt} + \text{area lt})/\text{area foramen}.$$

2.4 REFERENCES

The list of references was prepared according to the style of the Radiological Society of North America.

Figure 9a
Axial section through the foramen magnum employing a circular ROI to measure the area of the brainstem.

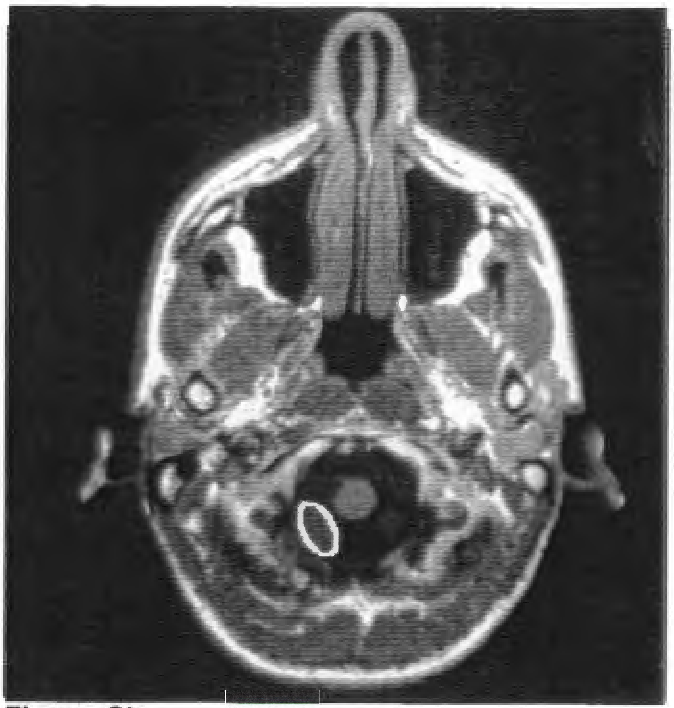


Figure 9b
Oval ROI outlines the right tonsil. The surface area is calculated.

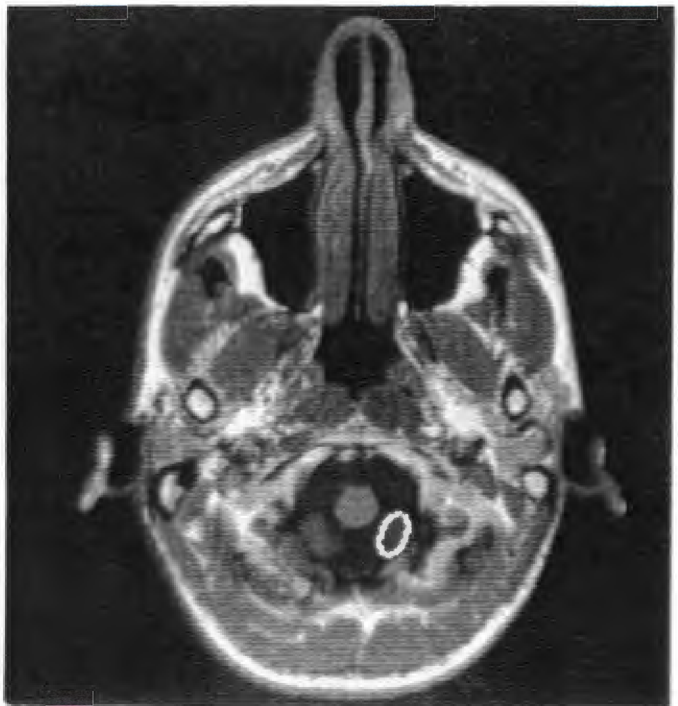


Figure 9c
A smaller oval ROI measures the surface area of the left tonsil.

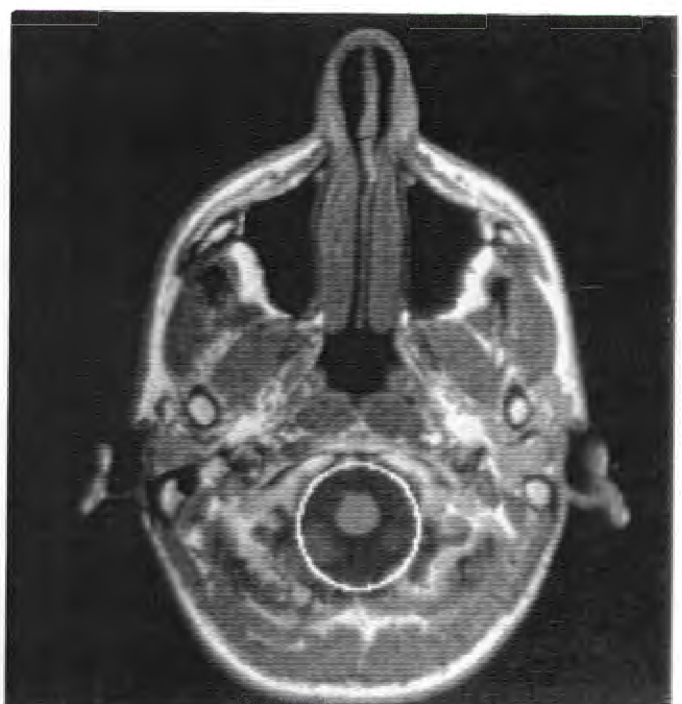


Figure 9d
A circular ROI is introduced over the cortical margin of the foramen magnum. An area measurement of the foramen is obtained.

2.5 STATISTICAL METHODS

2.5.1 SUMMARY

The study focused on the FMI, Tonsillar Level and the relationship between them. The summary of statistics (**Table 2**), shows the ranges, sample size and skews in the data. The distribution of the variables **Age** and **FMI** are symmetrical as the mean is virtually identical to the median. This is not so for **Tonsillar level** where the mean is greater than the median, suggesting a skew to the left. This is caused by the many subjects who have tonsils present (TAM*), but where the tonsils can not be measured below the foramen magnum.

The statistical approach was to find natural splits to explain the data more effectively. The possible splits included **Age, Sex and TAM**.

2.5.2 CONTINGENCY TABLE - TAM BY SEX

To investigate whether there was an gender effect in the TAM* group, a contingency table was set up (**Table 3**). Both variables are categorical with **TAM** being positive or negative and Sex being male or female. A Chi-squared statistic was calculated with 1 degree of freedom. The calculated value was smaller than the critical value at the 95% confidence level, and therefore the null hypothesis that there is no gender effect, was accepted.

2.5.3 CONTINGENCY TABLE FMI BY SEX

In **Table 4** the contingency table is made up of two variables. **Sex** being male and female and **FMI** broken up into 8 bands with an interval of 0.1. The interval decided on was based on Sturges' Rule. The Chi-squared value is smaller than the critical value at the 95% confidence level, with 7 degrees of freedom. By inspection it is clear that the FMI for both sexes follow the same bimodal distribution

2.5.4 TEST FOR DIFFERENCE IN MEAN FMI BY SEX

To test whether there is a significant difference between the mean **FMI** for male and **females**, with FMI being a continuous variable, a t-test for unknown but equal variances was performed. The calculated t-statistic was smaller than the critical value at the 95% confidence level, which means that the null hypothesis that there is no gender effect, was accepted **(Table 5)**.

2.5.5 TEST FOR DIFFERENCE IN MEAN AGE BY TAM

As in **Table 5**, the t-test is appropriate to test whether there is a significant difference between the mean **Age** for **TAM*** (positive) and **TAM**- (negative subjects) **(Table 6)**. The calculated t-statistic was smaller than the critical value at the 95% confidence level, which means that the null hypothesis that there is no TAM effect, was accepted.

2.5.6 TEST IF AGE IS A SIGNIFICANT INDICATOR OF THE FMI

Both the **FMI** and **Age** are continuous variables, and to test whether Age affects the FMI, simple linear regression was used (Table 7). The calculated F-statistic is smaller than the critical value which means that the null hypothesis that age does not affect the FMI, is accepted.

2.5.7 TEST FOR DIFFERENCE IN FMI BY TAM

The test for differences in the FMI for two groups lends itself to the t-test used before in **Tables 5** and **6 (Table 8)**. The sample is split into **TAM*** (positive) and **TAM**- (negative) subjects. The TAM positive group have a significantly higher FMI than the negative group, with the t-statistic being much larger than the critical value at the 95% confidence level. This seems to be a natural split in the data that breaks up the FMI distribution into two approximately normal populations.

2.5.8 CORRELATIONS BETWEEN THE FMI AND THE TONSILLAR LEVEL

The correlation between the **FMI** and the **Tonsillar Level** was run and the scatterplot produced. The correlation was 0.67, but the scatterplot suggested that one of the variables was not linear (Table 9). The Tonsillar Level seemed to have a logarithmic relationship. The variable was thus transformed, and the result was a linear scatterplot and a stronger correlation of 0.74 (Table 10). The FMI and the log of the Tonsillar Level was regressed using simple linear regression and a significant relationship was discovered in Table 12.

CHAPTER 3

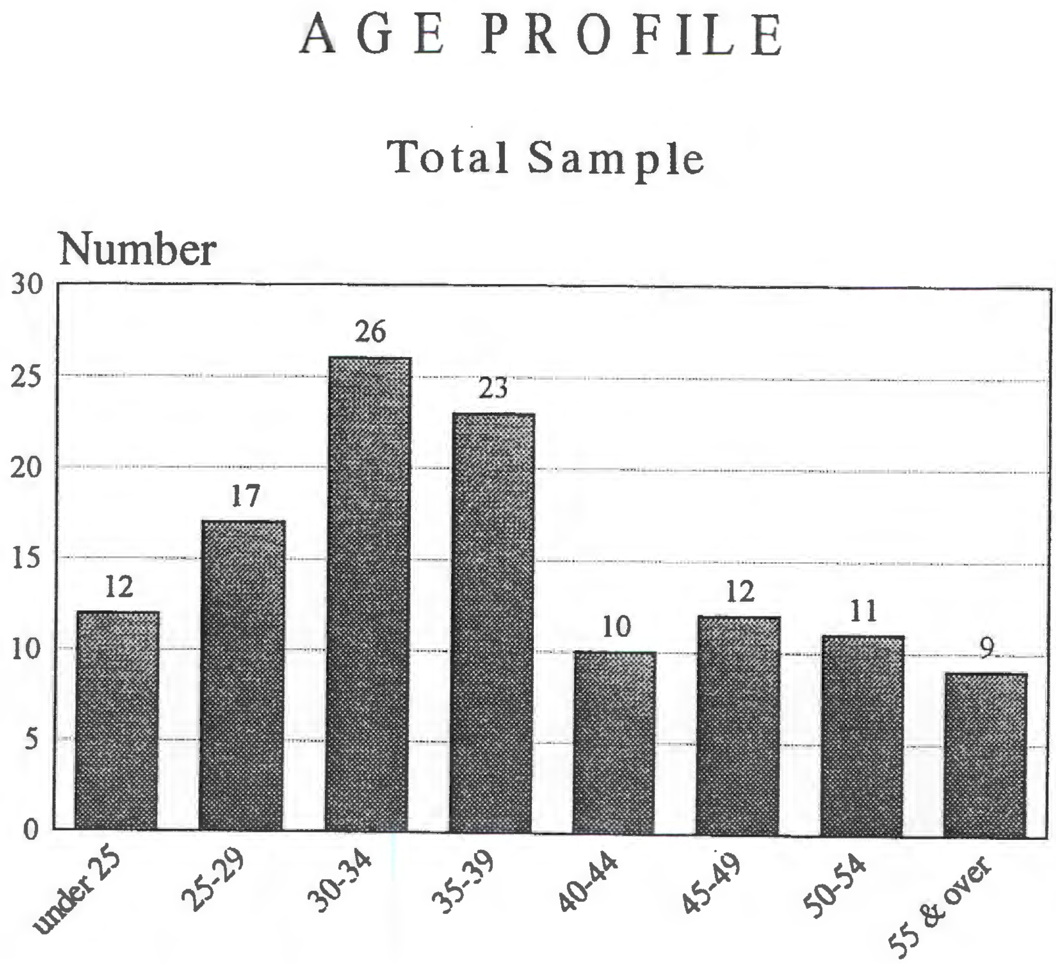
3. RESULTS

3.1 TOTAL SAMPLE

The mean age of the sample was 37 years, (N = 120, M = 60/F = 60). **(Table 2) (Graph 1)**. The cerebellar tonsils could be identified and measured on the axial section through the foramen magnum in 74 out of 120 cases (61%) (tonsillar area measurement possible {TAM*}) of which 40 (54%) were female and 34 (46%) male. In the remaining 46 cases (38,3%) the cerebellar tonsils did not reach the level of the foramen magnum (tonsillar area measurement negative {TAM-}) and only the distal brainstem was visualized on the axial scan **(Table 3)**.

3.2 NORMAL DISTRIBUTION OF THE FORAMEN MAGNUM INDEX

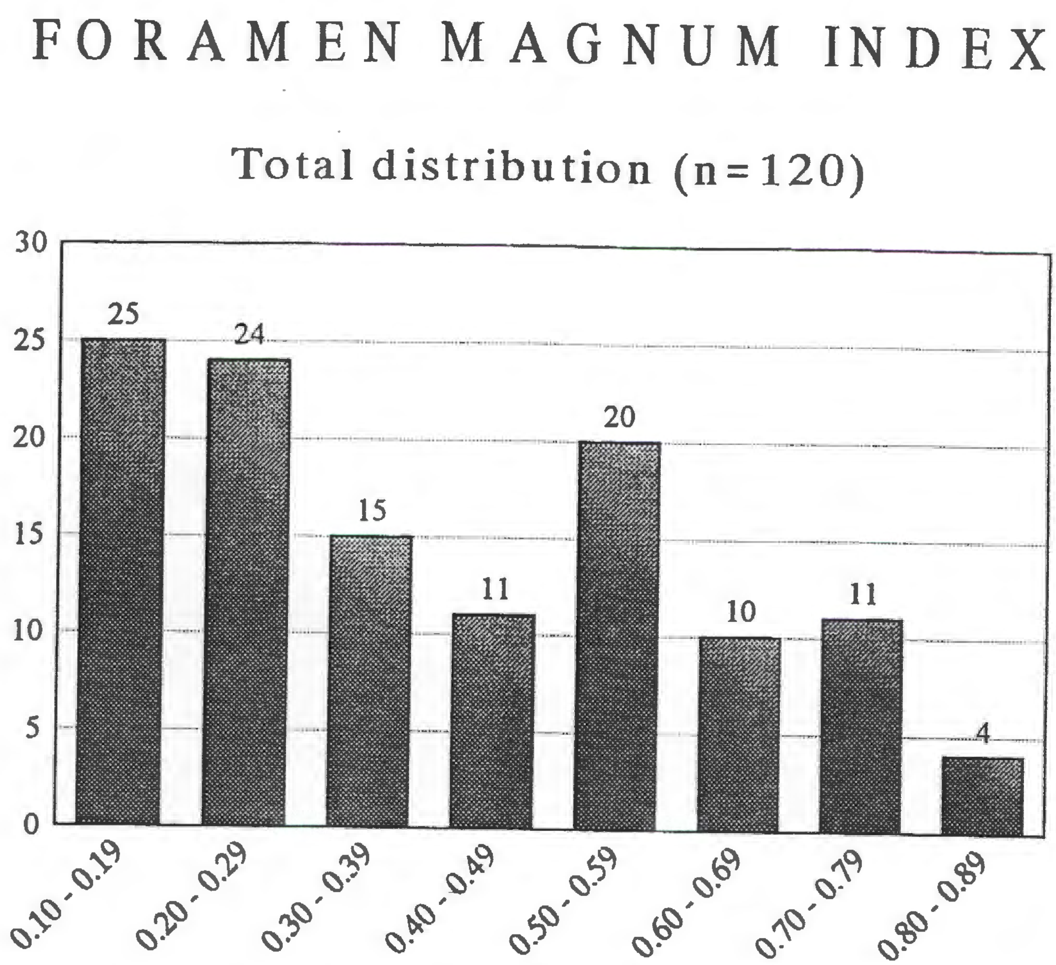
The variable FMI (ratio-area in tables) has a bimodal distribution which indicates the presence of two populations **(Graph 2)**. The mean was calculated at 0.4 and the median at 0.37. Since these two values are virtually identical, no skews exist in the sample. The range was indicated by a minimum of 0.12 (in the lower population) and a maximum of 0.85 (in the higher population). A standard deviation of 0.21 exists **(Table 2)**. The 95 percentile is 0.77.



Graph 1: Age bands

3.3 EVALUATION OF VARIOUS NATURAL SPLITS

In the presence of a bimodal distribution, it became necessary to evaluate several natural splits and i) sex ii) age and iii) Tonsillar area measurement possible/not possible (TAM*/-) were used as discriminators.



Graph 2: FMI Intervals

3.3.1 SEX AS A DISCRIMINATOR

The hypothesis that the number of females that are TAM* equals the number of males that are TAM* was tested. From **Table 3** a Chi squared value of 1.27 was computed with 1 degree of freedom at the 95% level. This is less than the critical value of 3.84 which indicates that there is no difference between the female and male groups regarding individuals where it is possible to measure the cerebellar tonsils within the foramen magnum.

TABLE 2

Summary: Statistics for all variables (n = 120)

	Age	Area Cord cm^2	Area Right cm^2	Area Left cm^2	Area Sum cm^2	Area For cm^2	Rat_ Area	Ton_ Lv cm
Sample size	120	120	10	120	120	120	120	73
Minimum	18	1	0	0	1	4.3	0.12	0
Maximum	66	2.8	3.8	4.3	10.9	13.5	0.85	12.5
Median	36	1.5	0.95	0.7	3.2	8.8	0.37	0
Mean	37.36	1.61	1.02	0.94	3.58	8.68	0.4	1.35
Std Dev	10.84	0.31	1.05	1.04	2.15	1.66	0.21	2.21

TABLE 3

Contingency table - TAM by sex (n = 120)

	SEX		Total TAM
TAM	Female	Male	
"-"	20	26	46
"*"	40	34	74
Total by sex	60	60	120

Chi-squared statistic = 1.27
Critical value (df = 1,95%) = 3.841

The FMI distribution was compared across sexes to identify differences **(Table 4)**. An interval size of 0.1 was calculated using Sturges rule:

$$[Max-Min]/[1 + 1.44*\ln n]$$

By inspection, the distributions were virtually identical with bimodal distributions **(Graph 3)**. A Chi-squared test confirmed this with a calculated value of 10 which is below the critical value 14.067 (7 degrees of freedom).

TABLE 4

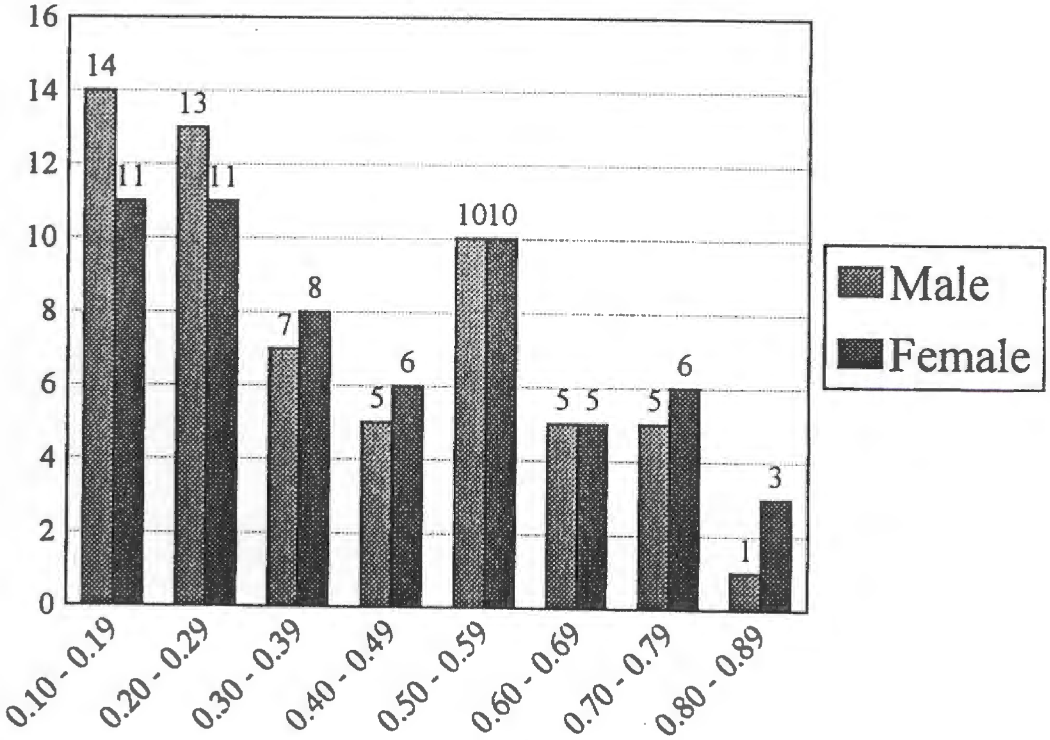
Contingency Table - FMI by sex (n = 120)

	Sex		*Total by Index*
FMI	*Female*	*Male*	
0.10 - 0.19	*11*	*14*	*25*
0.20 - 0.29	*11*	*13*	*24*
0.30 - 0.39	*8*	*7*	*15*
0.40 - 0.49	*6*	*5*	*11*
0.50 - 0.59	*10*	*10*	*20*
0.60 - 0.69	*5*	*5*	*10*
0.70 - 0.79	*6*	*5*	*11*
0.80 - 0.89	*3*	*1*	*4*
Total by Sex	*60*	*60*	*120*

A further test was conducted to see if the FMI values for females and males were

FORAMEN MAGNUM INDEX

Split by Sex



Graph 3: FMI Intervals

the same (**Table 5**). A t-test with a hypothesis that the mean FMI of the female group was equal to the mean FMI of the male group was conducted. The t-statistic was calculated at 1.12 which was once again less than the critical value of 1.98. The null hypothesis is accepted that there is no difference in the means of the FMI between the male and female groups and sex is therefor not a factor in natural distribution of the FMI.

TABLE 5

Test for difference in mean FMI by sex (n = 120)

	Sex		Difference
	Female	Male	
Mean	0.423	0.381	0.042
Std Dev	0.214	0.197	0.205
Sample size	60	60	120

t-Statistic = 1.124
Critical Value = 1.98

3.3.2 AGE AS A DISCRIMINATOR

The ability to measure the cerebellar tonsils within the neural foramen depends on the vertical position and therefore whether the patient falls into the TAM*/TAM- group. The difference in age between the two groups was compared using a t-test (Table 6). The calculated t-statistic came out as 0.63, which is lower than the critical value of 1.98, which indicates that the hypothesis that the age for the two groups is the same, is accepted. In this population, therefore, age has no effect on the position of the tonsillar position relative to the the plane of the foramen magnum.

To test whether age is a significant variable in explaining the FMI, the null hypothesis that age has no effect on FMI was tested. As both variables were sufficiently continuous, it was possible to linearly regress these to establish the relationship **(Section 2.4.6)**. From **Table 7** the calculated F-statistic was 0.54 which is smaller than the 95% value of 2.75. As a result, the null hypothesis that age has no effect on the FMI, is accepted.

TABLE 6

Test for difference in mean age by TAM (n = 120)

	TAM		***Difference***
	"-"	*"*"*	
Mean	*38.230*	*36.970*	*1.260*
Std Dev	*11.597*	*10.386*	*11.0008*
Sample Size	*60*	*60*	*120*

t-Statistic = 0.627
Critical Value = 1.98

3.3.3 TONSILLAR AREA MEASUREMENT AS A DISCRIMINATOR (TAM)

As expected, the FMI was significantly higher in the TAM* group (Table 8). A t-test was used to substantiate this assumption. The calculated value was established as -16.58 which is larger negative than the critical value of -1.98. Thus the hypothesis that the mean FMI is the same for both groups is rejected. Clearly the presence of the cerebellar tonsils within the foramen magnum on an axial section through this level, is responsible for the bimodal distribution of the FMI.

TABLE 8

Test for difference in FMI by TAM (n = 120)

FMI	***TAM***		***Difference***
	"-"	*"*"*	
Mean	*0.202*	*0.526*	*-0.324*
Std Dev	*0.050*	*0.163*	*0.132*
Sample size	*46*	*74*	*120*

t-Statistic = -16.58
Critical Value = -1.98

3.4 RELATIONSHIP BETWEEN THE AREA OF THE FORAMEN MAGNUM AND THE TONSILLAR LEVEL

The correlation between the area of the foramen magnum and the tonsillar level is 0.16. There is thus no connection between the size of the foramen and the position of the tonsils below the foramen magnum.

3.5 RELATIONSHIP BETWEEN THE FMI AND TONSILLAR LEVEL

The correlation of the FMI (Rat_Area) and the tonsillar level (Ton_Lv) is significant at the 99.9% level (Table 9). There is a strong relationship between the two variables

TABLE 9

Correlation Table for TAM (n=73)*

	Area_For	*Rat-Area*	*Ton_Lv*
Area_For	*1*	*0.069*	*0.16*
Rat_Area	*0.069*	*1*	*0.672*
Ton_Lv	*0.16*	*0.672*	*1*

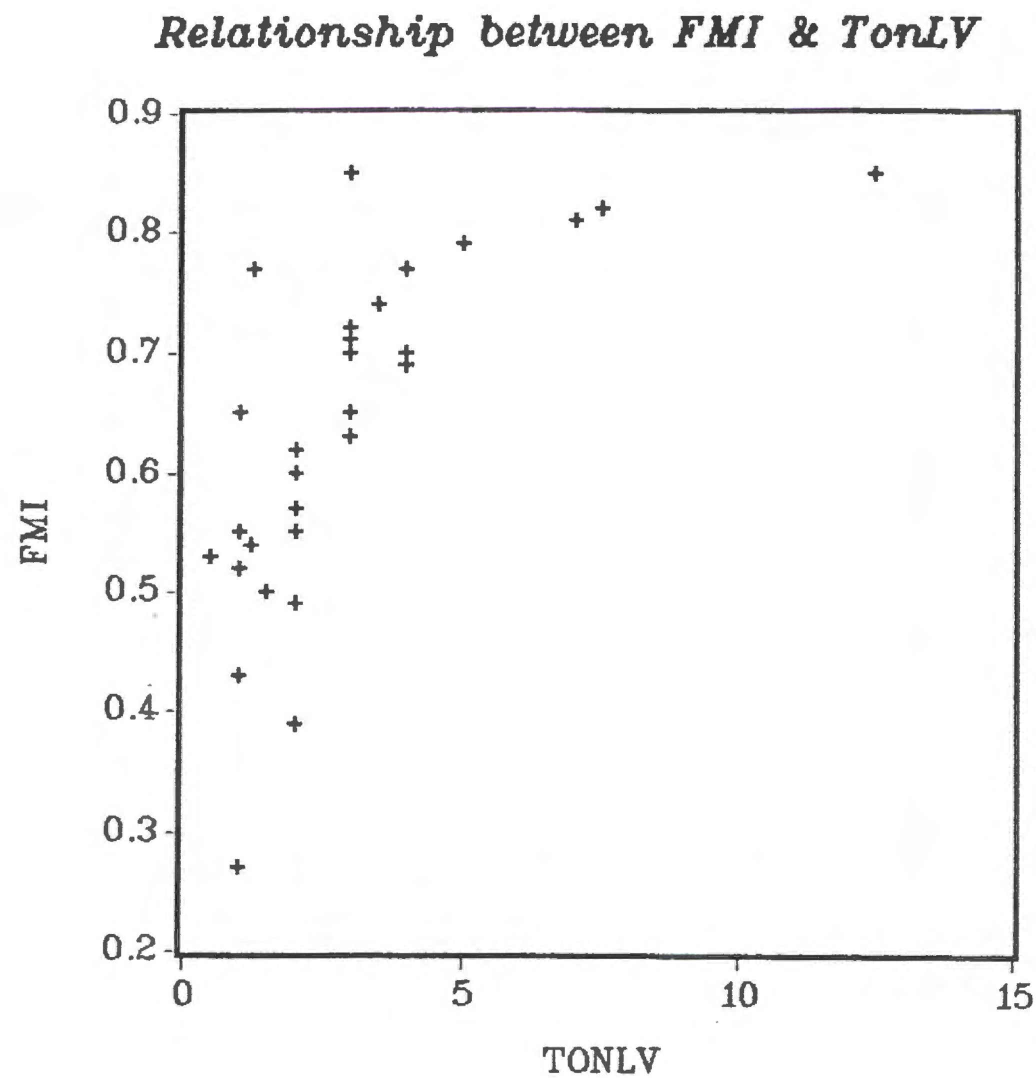
From **Graphs 4** and **5** it is clear that the relationship between tonsillar level and FMI is not linear. Consequently the variable Ton_Lv was transformed to its natural logarithm and then correlated with the FMI. Only values where the tonsillar level was greater than 0 were used, as 0 cannot be transformed. Amongst the remaining 32 observations, after the above exclusions, the relationship proved even stronger with a correlation of 0.74 **(Table 10) (Graph 6)**.

The variables were regressed against each other **(Section 2.4.8)**. The model that resulted was:

Rat_Ar = 0.514 + 0.146 * ln(Ton_Lv) **(Table 12)**

The model is highly significant. The F-statistic of 35.6 is greater than the critical value of approximately 4 and explains 54% of all variation in Rat_Ar.

GRAPH 4


Relationship between FMI & TonLV
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
FMI
0
5
10
15
TONLV

GRAPH 5

RELATIONSHIP BETWEEN FMI TON _LV

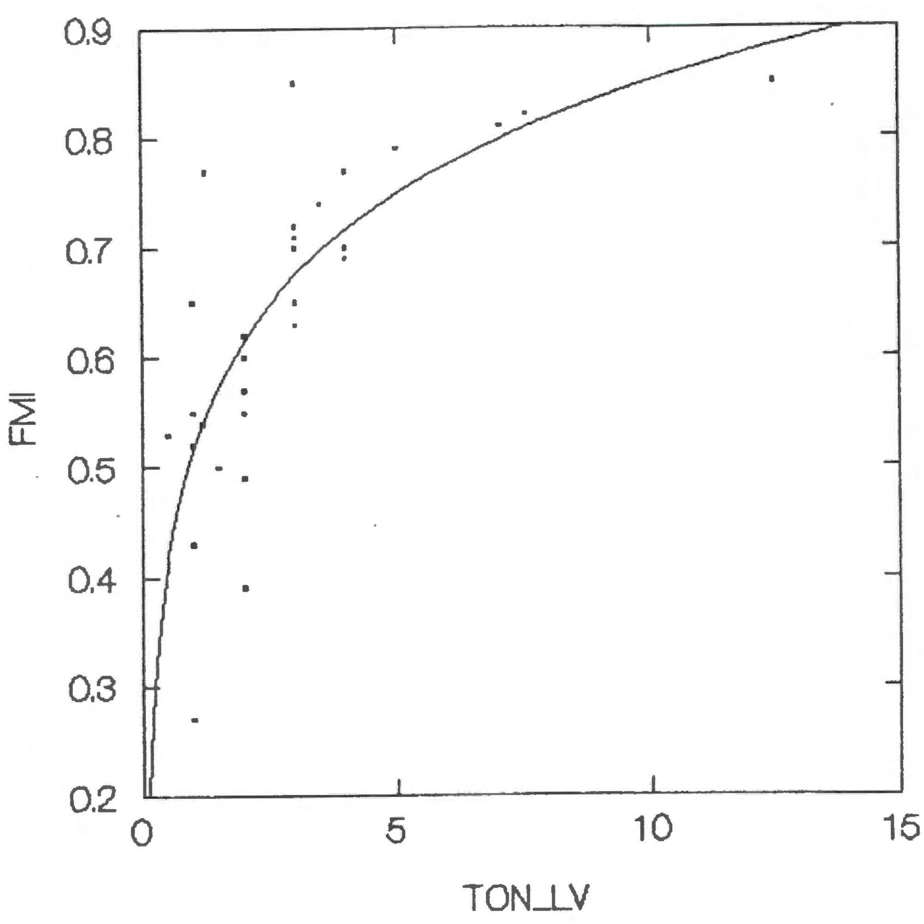
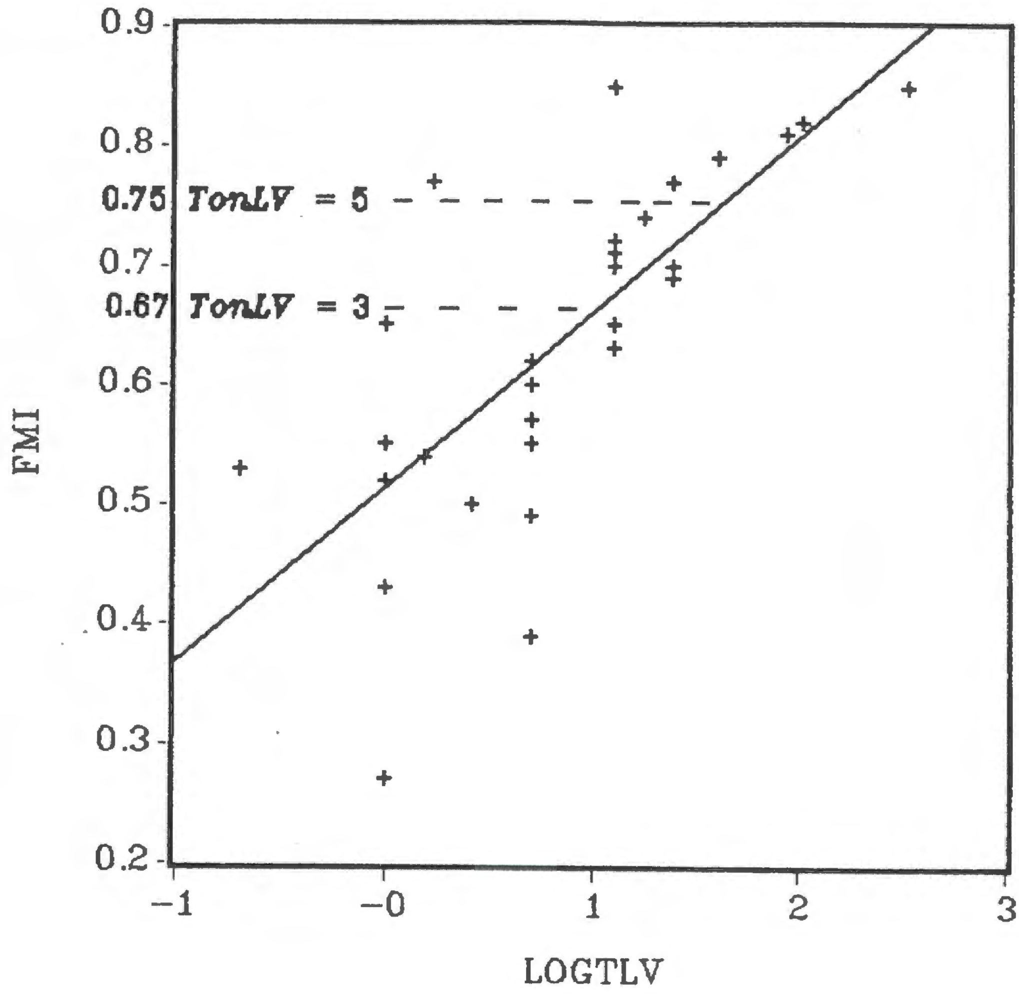


TABLE 10

Correlations where Ton_Lv > 0 (n=32)

	Rat_area	Ton_Lv	LN(Ton_Lv)
Rat_Area	1	0.67	0.74
Ton_Lv	0.67	1	0.89
LN(Ton_Lv)	0.74	0.89	1

Relationship between FMI & Tonsil Level



GRAPH 6

CHAPTER 4

4. DISCUSSION

4.1 THE SIGNIFICANCE OF VERTICAL POSITION OF THE CEREBELLAR TONSILS

Problematic aspects of the Chiari malformations have provided the stimulus for numerous investigations in posterior fossa morphology over the past century. Unquestionably, the recent impetus to these studies has been the direct result of the advent of magnetic resonance imaging and its advantageous application to neuroanatomy.

The difficulties, as well as the present status of clinical and morphologic correlation peculiar to the Type I disorder have already been alluded to in **Section 1.4**, and centre on the definition of cerebellar tonsillar position vis-a-vis the foramen magnum, together with the existence of a population of individuals whose 'abnormality' is asymptomatic.[31]

During the course of routine examination of the craniocervical junction in this institution, it was observed that in some patients whose subjective symptomatology included headaches and dizziness, low-normal tonsillar position was associated with a perceptible reduction in the CSF signal of the cerebellomedullary cistern, suggesting crowding of neural structures at the level of the foramen magnum. The natural consequence of this observation presented a hypothesis: that neural crowding, inevitable beyond a certain degree of tonsillar herniation (ie. definite Chiari Type I), also occurs in some instances of low-normal tonsillar position.

To test the hypothesis, the relationship between surface area of neural tissue and that of the foramen magnum, the **Foramen Magnum Index or FMI**, was quantitated in a normal sample. Statistical correlation of the **FMI** with tonsillar position, age and sex was then performed, as well as that of foramen magnum surface area and tonsillar position.

4.2 UNDERLYING DISTRIBUTION OF THE FORAMEN MAGNUM INDEX (FMI)

The normal distribution of the **FMI** is represented by a bimodal curve, 0.77 as the 95th percentile. Two distinct populations were identified and, according to expectation, these represent a group in the range below the mean where the tonsils did not appear within the boundaries of the foramen magnum on axial section (TAM-). Only the surface area of the medulla (or cervicomedullary junction) was available for measurement, and constituted the total sum of neural tissue in the **FMI** formula. Conversely, the TAM* individuals whose cerebellar tonsils were present within the foramen magnum, constituted the group in the higher range above the mean.

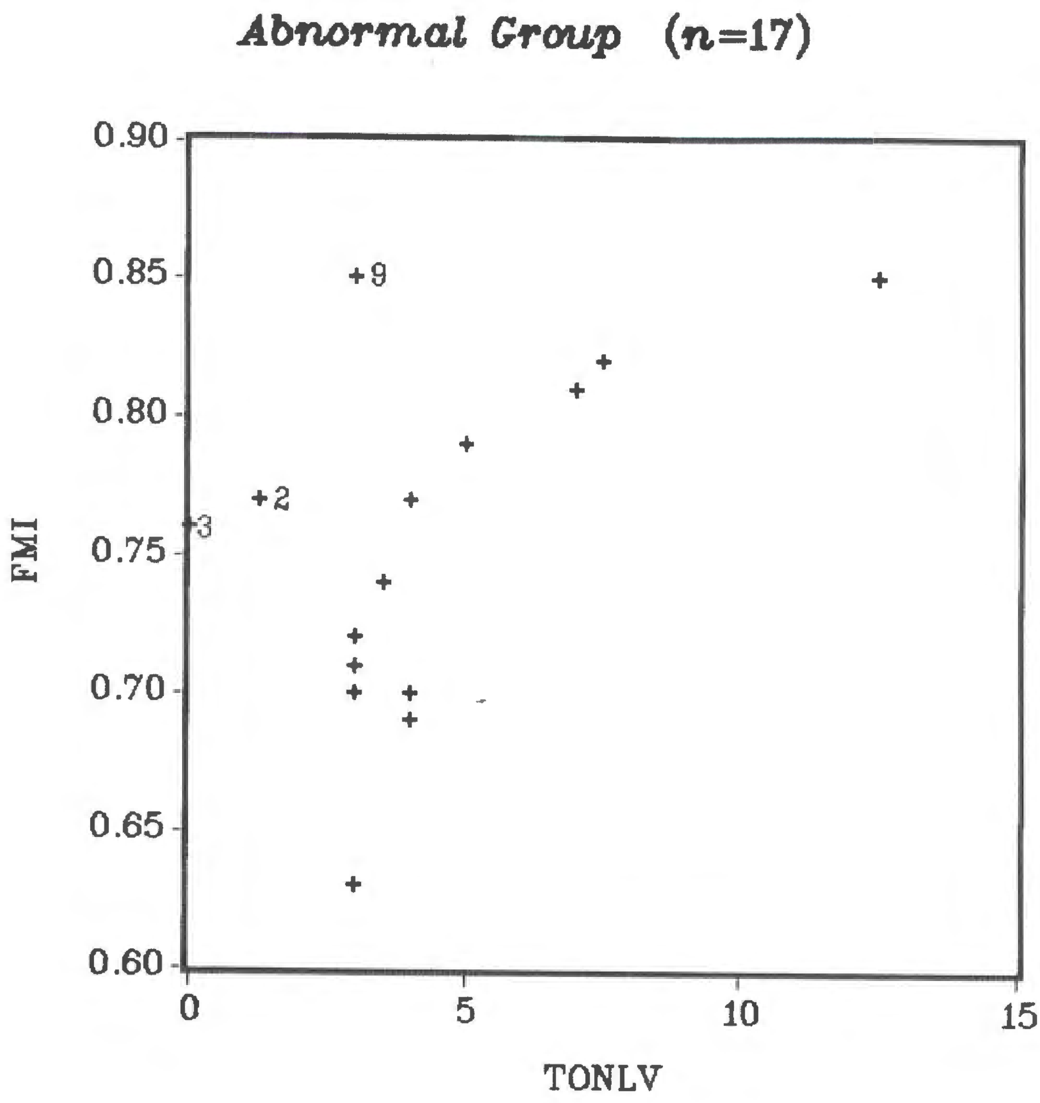
4.3 RELATIONSHIP BETWEEN THE AREA OF THE FORAMEN MAGNUM AND THE TONSILLAR LEVEL

Statistically, no correlation between the position of the cerebellar tonsils and the size of the foramen magnum could be demonstrated. This is to be expected against the background of the strong relationship between the tonsillar position and the **FMI**. Thus, low tonsillar position is associated with crowding of the foramen magnum and is not due to inferior displacement through an exceptionally spacious aperture.

4.4 RELATIONSHIP BETWEEN THE FMI AND THE TONSILLAR LEVEL

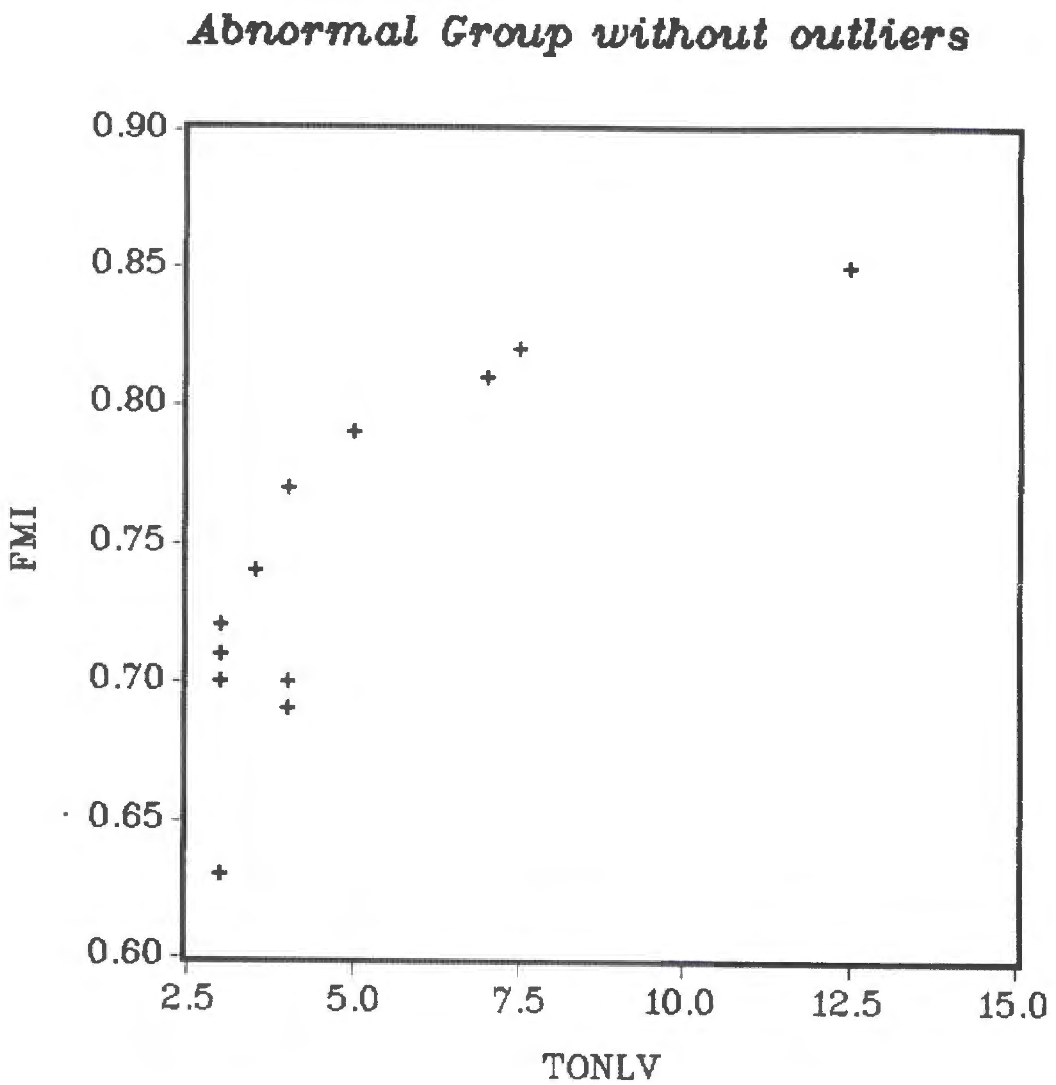
A correlation of 0.672 between the **FMI** and the tonsillar level indicates a strong relationship between the two variables. When the variable "tonsillar level" (Ton_Lv) is transformed to its natural logarithm, the relationship is even stronger (correlation of 0.74). The conventional diagnosis of Chiari I malformation requires a tonsillar level of 5mm (or more) below the foramen magnum (see **Section 1.4.1**). Foramen magnum morphometry permits an alternative definition: the malformation is present if the **FMI** is 0.75 or above. Protrusions of 3-5mm which of uncertain significance can be translated into an **FMI** range of 0.67-0.75 **(Graph 6)**.

A finding of this study of particular interest, pertains to a group of 17 individuals who were identified because of a tonsillar level exceeding 3mm, or a **FMI** exceeding 0.67 **(Graph 7)**. When studying this graph, it becomes clear that there



GRAPH 7

are three distinct outliers affecting the correlations and the statistical relationship, these being identities 2, 3 and 9. When these are removed from the abnormal group, a stronger logarithmic relationship is re-established (Graph 8).



GRAPH 8

4.5 CORRELATION WITH SEX

It has long been recognized that Chiari II malformations are slightly more common in female than in male patients [32]. In a recent study it was also estimated that a female preponderance of about 40% exists in the Type I disorder.[30]

In the present series, no significant statistical difference could be established in the group where the cerebellar tonsils appeared within the foramen magnum (TAM*). A Chi-squared value of 1.27 was below the critical value of 3.84. Although a female preponderance of 40 to 34 was demonstrated, the **FMI** showed virtual identical male/female bimodal distributions, and the Chi-squared test with a calculated value of 10 was again under the critical value of 14.067. Nevertheless, three females had a **FMI** above 0.8, with only one male in the same category. Despite a female-male means of 0.42 and 0.38, the t-test showed no significant difference between these two values.

Statistical evidence notwithstanding, a number of interesting observations emerged:

a) A female preponderance of 40 to 34 exists in the group where tonsillar measurement was possible within the foramen magnum.

b) For those individuals with a **FMI** above 0.8, a female/male ratio of 3:1 exists.

c) In the group of definite Chiari I malformation (tonsillar level > = 5mm) the female/male ratio is 4:1. In the group regarded as abnormal by **FMI**,(>0.75) (see Table 10 below), the female preponderance was 7:1

The data are therefore consistent with previously reported studies in which a female preponderance exists with regard to tonsillar position relative to the foramen magnum.[31]

4.6 CORRELATION WITH AGE

The null hypothesis that no change in the position of the cerebellar tonsils occurs with age, is now claimed to be statistically disproved.[6] Linear correlation between tonsillar position and age does not exist. In fact, significant differences between the younger and older age groups, as well as the uniformity in tonsillar position seen in the middle age-groups, suggest that the relationship between tonsillar position and age is nonlinear.

According to Mikulis et al,[6] cerebellar tonsils located more than 6mm below the foramen magnum in the first decade of life are more than 2 standard deviations beyond the range of normal; in the next two decades, the location of tonsils more than 5mm below the foramen magnum is abnormal. Between ages 30 and age 79 years, the abnormal distance is 4mm below the foramen, and at age 80 and older, 3mm. These values are in general agreement with other MR reports.[26 30]

It is suggested that the true relationship between tonsillar position and age has a high slope (rapid tonsillar ascent) during the early decades, with flattening of the curve during adulthood and middle age and finally a second high slope during the later decades **(Fig 3)**.[6] The position of the tonsils below the foramen magnum during embryonic development and early life is normal. As the calvarium expands in response to the trophic influence of the rapidly enlarging contents of the posterior fossa,[33] the volume of the posterior fossa tends to lag behind that of the growing brainstem and cerebellum and cannot, therefore, adequately contain these structures. Continued growth of the neurocranium after cessation of brain growth results in stable accommodation of cerebellum and tonsils. In old age, the normal process of volumetric shrinkage ensues, leading to a second phase of shift in the position of the cerebellar tonsils.[34]

In the present study, ages range from 18 to 66 years, so that the sample clearly falls into the stable phase of the age/position relationship curve **(Fig 3)**, and as is to be expected, no effect of age upon the **FMI** was found (t-statistic values of 0.63 versus 1.98).

4.7 SENSITIVITY OF AN ABNORMAL FMI IN THE ASYMPTOMATIC POPULATION.

In the sample group of 120 healthy volunteers, 5 individuals (4 female, 1 male) were identified as having a Chiari Type I malformation according to the conventional definition (ie. cerebellar tonsils > = 5mm below foramen magnum), a finding consistent with the reports of other investigators.[30]

By comparison, use of the **FMI** identified the same identities, together with an additional 3 individuals (7 female, 1 male) **(Table 10)**. Analyses of identities 2, 3 and 9 **(Section 4.4)(Table 1)** shows the following:

Identity 2 : Tonsillar level: 1.25 ; FMI: 0.77 (female)

Identity 3 : Tonsillar level: 0 ; FMI: 0.76 (female)

Identity 9 : Tonsillar level: 3.00 ; FMI: 0.85 (female).

Using the definition of Chiari I malformation based on **FMI**, it is clear that all three patients should be classified as abnormal, yet cerebellar tonsillar levels do not fall within the abnormal range. Identity 3 is particularly interesting, **Fig 10a** clearly shows foraminal crowding, but the cerebellar tonsils can not be identified below the foramen magnum on **Fig 10b**. Identity 9 has the maximum value of **FMI** (.85) but the tonsillar level is 3mm below, which is the lowest value for an uncertain diagnosis.

Hence there appears to be a (sub)group of normal individuals (3/120) where a significant degree of neural crowding within the foramen magnum is associated with tonsils that are at or only slightly below the foramen magnum. Since the **FMI** identifies no false conventionally positive cases of low tonsils, its specificity may reasonably be assumed. However, this can only be assessed in relation to symptomatic subjects, and the Index is thus intended to provide the neurologist and clinician with a quantitative means of identifying these patients.

TABLE 11

Sex comparison by technique

	Tonsil Level > =5	*Foramen Magnum Index > =0.75*
Female	*4*	*7*
Male	*1*	*1*

Figure 10a
Axial section through the foramen magnum with oval ROI outlining the foramen. Cerebellar tonsils are visible within the foramen and an FMI of 0.76 was calculated.

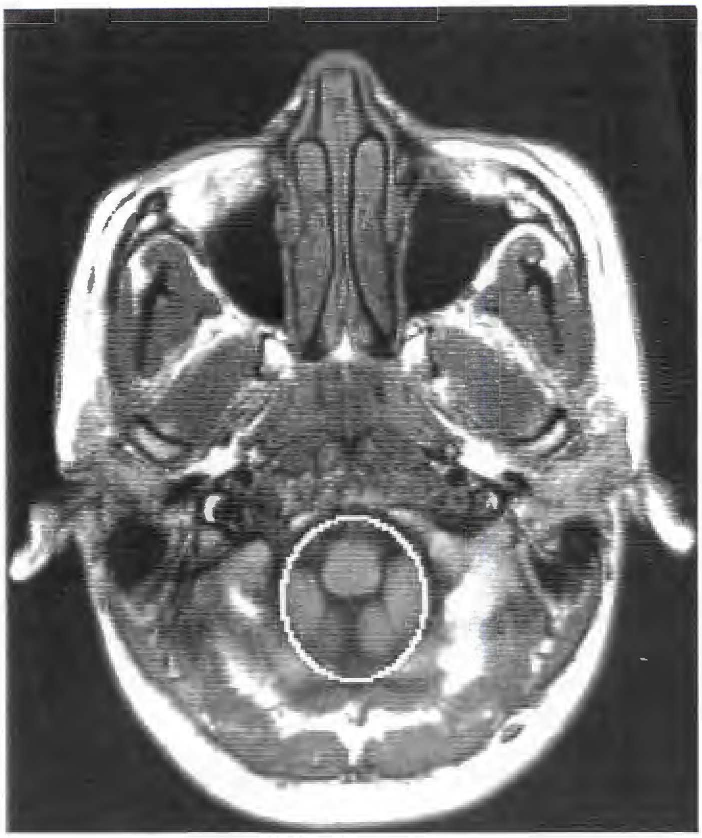


Figure 10b
Parasagittal section through the tonsil. The plane of the foramen magnum is marked by the oblique black line. The tonsil does not appear below this level.

CHAPTER 5

5. SUMMARY AND CONCLUSION

The expression of a ratio between neural tissue and available space at the level of the foramen magnum, constitutes a rational alternative technique to that of vertical tonsillar measurement in assessment of structures in the caudal aspect of the cerebellomedullary cistern. The validity is borne out by analysis of the statistical data.

Strong correlation exists between the FMI and vertical tonsillar position below the level of the foramen; however, the method is designed specifically to examine the presence or absence of neural crowding in the population, selected on routine sagittal T1 images, whose tonsillar tips lie at or within the level of the foramen.

Using the FMI (95th percentile = 0.77), the majority of the relevant sample displayed a mean of 0.4, which is significantly below the calculated range (0.67-0.75) for the Chiari I malformation. It also identified a sub-group of individuals having a ratio above 0.75, in whom the tonsillar level, by conventional definition, is not abnormal. It is therefore predicted that the technique will contribute to the sensitivity of the diagnosis of asymptomatic Chiari I malformation, as well as to the management of a clinical variant of the disorder, namely, foraminal crowding without ectopia.

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APPENDIX A

TABLES

TABLE 1: RESULTS FOR ALL RESPONDENTS

ID	SEX	AGE	AREA C	AR RT	AR LT	AR SUM	AR FOR	RAT AR	P CORD	P RT	P LT	P SUM	P FOR	RAT P	TON LV
1	F	27	1.5	2.3	1.7	5.5	11.1	0.5	221	325	245	791	1589	0.5	1.5
2	F	29	1.5	2.4	1.9	5.8	7.5	0.77	221	345	265	831	1075	0.77	1.25
3	F	24	1.9	2.7	3.2	7.8	10.3	0.76	277	379	455	1111	1465	0.76	0
4	F	45	1.2	1.9	1.3	4.4	10.3	0.43	177	270	186	633	1465	0.43	1
5	F	36	1.5	0	0	1.5	6.1	0.25	221	0	0	221	865	0.26	
6	F	39	1.5	1.5	2.1	5.1	9.4	0.54	221	217	299	737	1337	0.55	0
7	M	31	1.5	0	0	1.5	9.8	0.15	221	0	0	221	1395	0.16	
8	M	52	1.5	0	0	1.5	10.3	0.15	221	0	0	221	1365	0.15	
9	F	30	1.5	2.3	2	5.8	6.8	0.85	221	323	285	829	969	0.86	3
10	M	35	1.9	1.6	1.8	5.3	9.8	0.54	277	233	254	764	1399	0.55	1.2
11	F	18	1.4	2.5	2.3	6.2	10.1	0.61	177	307	285	769	1247	0.62	0
12	F	46	1.4	1	0	2.4	6.2	0.39	177	125	0	302	765	0.39	0
13	F	38	1.4	1.5	0	2.9	7.9	0.37	177	197	0	374	973	0.38	0
14	F	54	1.8	3.8	3	8.6	10.1	0.85	221	447	375	1073	1267	0.85	12.5
15	F	60	1.4	0	0	1.4	6.5	0.22	177	0	0	177	807	0.22	
16	F	39	2.5	2.2	3	7.7	9.7	0.79	315	277	375	967	1205	0.79	5
17	F	27	1.7	0	0.6	2.3	8.3	0.28	207	0	75	282	1023	0.28	0
18	F	29	1.4	0	0	1.4	8.3	0.17	177	0	0	177	1023	0.17	
19	F	31	2.1	2.3	1.7	6.1	10.1	0.6	261	285	207	753	1247	0.6	2
20	M	49	1.8	0	0	1.8	7.8	0.23	221	0	0	221	969	0.23	
21	F	24	1.4	0	0	1.4	4.3	0.33	177	0	0	177	535	0.33	
22	M	31	1.4	0	0	1.4	7.9	0.18	177	0	0	177	973	0.18	
23	F	40	1.4	0	1.5	2.9	8.8	0.33	177	0	189	366	1093	0.33	0
24	M	35	1.3	1.5	1.4	4.2	9.7	0.43	163	185	173	521	1201	0.43	0
25	M	45	1.8	0.8	1.1	3.7	9.2	0.4	221	100	139	460	1139	0.4	0
26	F	31	2.3	2.4	2.4	7.1	10.2	0.7	291	296	292	879	1267	0.69	4
27	M	31	1.4	0	0	1.4	8.7	0.16	177	0	0	177	1083	0.16	
28	F	33	1.4	0.6	0	2	8.3	0.24	177	80	0	257	1031	0.25	0
29	F	31	11.8	0	0.7	2.5	9.2	0.27	221	0	83	304	1139	0.27	1
30	F	31	2.1	2.6	2.4	7.1	9.2	0.77	259	323	303	885	1139	0.78	5
31	F	50	1.5	0	0	1.5	8.3	0.18	185	0	0	185	1023	0.18	
32	F	28	1.4	1.8	1.4	4.6	8.8	0.52	177	225	178	580	1093	0.53	1
33	M	56	1.8	0	0	1.8	6.9	0.26	221	0	0	221	853	0.26	
34	M	43	1.9	0	0	1.9	10.2	0.19	241	0	0	241	1267	0.19	
35	F	59	1.4	0	0	1.4	7	0.2	177	0	0	177	869	0.2	
36	M	42	2.4	0	0	2.4	7.4	0.32	293	0	0	293	919	0.32	
37	M	31	1.4	0	0	1.4	7	0.2	177	0	0	177	865	0.2	
38	F	29	1.4	0	0	1.4	9.2	0.15	177	0	0	177	1139	0.16	
39	M	34	1.4	2	1.2	4.6	8.8	0.52	177	243	143	563	1085	0.52	0
40	F	38	1.7	0	1.8	5.3	8.5	0.62	207	229	225	661	1053	0.63	2
41	M	63	1.4	0	0	1.4	6.2	0.23	177	0	0	177	765	0.23	
42	M	54	1.4	1.8	0	3.2	9.7	0.33	177	219	0	396	1197	0.33	0
43	M	30	1.8	2.4	2.3	6.5	11.8	0.55	218	297	279	794	1465	0.54	1
44	F	44	1.4	0	0	1.4	10.7	0.13	177	0	0	177	1329	0.13	
45	F	32	1.4	0	0	1.4	7.4	0.19	177	0	0	177	923	0.19	
46	F	40	1.4	0	0	1.4	4.7	0.3	177	0	0	177	585	0.3	
47	F	50	1.8	0	0	1.8	6.9	0.26	221	0	0	221	853	0.26	
48	F	36	2.5	2.7	2.7	7.9	10.7	0.74	305	331	334	970	1329	0.73	3.5
49	F	33	1.4	0	0	1.4	7.4	0.19	177	0	0	177	923	0.19	
50	F	34	1.4	0.9	1.4	3.7	5.4	0.69	177	113	169	459	665	0.69	4
51	F	44	1.7	1.8	0.8	0.8	4.3	0.52	214	227	103	544	1023	0.53	1
52	F	36	1.8	1.4	0	3.2	7.4	0.43	221	169	0	390	923	0.42	0
53	F	29	2	0	0	2	7.4	0.27	246	0	0	246	923	0.27	
54	M	20	1.4	0	0	1.4	4.7	0.3	177	0	0	177	581	0.3	
55	M	39	1.4	0	0	1.4	6.6	0.21	177	0	0	177	815	0.22	
56	F	47	1.8	1.5	0	3.3	7.9	0.42	221	189	0	410	973	0.42	0
57	F	59	1.8	3.1	2.5	7.4	11.3	0.65	221	378	314	913	1395	0.65	1
58	F	32	1.4	1	0.8	3.2	9.7	0.33	177	123	103	403	1205	0.33	0
59	F	53	1.4	1.1	0.7	3.2	6.1	0.52	179	133	89	401	755	0.53	0

TABLE 1 (contd): RESULTS FOR ALL RESPONDENTS

ID	SEX	AGE	AREA C	AR RT	AR LT	AR SUM	AR FOR	RAT AR	P CORD	P RT	P LT	P SUM	P FOR	RAT P	TON LV
60	M	51	1.1	0	0	1.1	6.2	0.18	137	0	0	137	765	0.18	
61	F	26	1.5	2.8	2.4	6.7	11.8	0.57	189	346	299	834	1465	0.57	2
62	F	33	1.4	0	0	1.4	8.3	0.17	177	0	0	177	1031	0.17	
63	F	47	1.4	1.3	0	2.7	6.6	0.41	177	167	0	344	815	0.42	0
64	F	48	1.4	0	0	1.4	7.9	0.18	177	0	0	177	973	0.18	
65	M	66	1.8	0.8	1.8	4.4	8.3	0.53	221	103	223	547	1031	0.53	0.5
66	M	22	1.4	0	0	1.4	9.7	0.14	177	0	0	177	1201	0.15	
67	M	31	1.4	0	0.7	2.1	10.2	0.21	177	0	92	269	1267	0.21	0
68	F	33	1	0	0	1	8.3	0.12	129	0	0	129	1031	0.13	
69	M	52	1.7	1	1.6	4.3	8.2	0.52	177	101	170	448	865	0.52	0
70	F	54	1.4	1.8	1.6	4.8	8.8	0.55	177	227	203	607	1093	0.56	2
71	M	26	1.8	1.4	0.9	4.1	10.7	0.38	221	169	115	505	1329	0.38	0
72	M	37	1.8	0	0	1.8	10.8	0.17	221	0	0	221	1335	0.17	
73	M	28	1.4	0	0	1.4	7.9	0.18	177	0	0	177	973	0.18	
74	M	33	1.4	1.6	1.9	4.9	9.2	0.53	177	201	241	619	1143	0.54	0
75	M	39	1.8	0.7	1	3.5	6.6	0.53	221	87	125	433	815	0.53	0
76	M	44	1.8	0	0	1.8	7	0.26	221	0	0	221	869	0.25	
77	F	36	1.4	0	0	1.4	7.4	0.19	177	0	0	177	919	0.19	
78	M	36	1.4	0	0	1.4	6.5	0.22	177	0	0	177	811	0.22	
79	M	29	1.8	2.4	2.4	6.64	9.2	0.72	221	303	296	820	1139	0.72	3
80	M	41	1.8	1.7	1.6	5.1	7.3	0.7	221	209	199	629	907	0.69	3
81	M	48	1.8	1.8	0.9	4.5	8.8	0.51	221	227	115	563	1093	0.52	0
82	M	36	1.8	0.8	0	2.6	9.2	0.28	217	101	0	318	1143	0.28	0
83	M	43	1.8	0	0	1.8	8.8	0.2	221	0	0	221	1093	0.2	
84	F	33	1.4	0.6	1.3	3.3	9.7	0.34	177	77	157	411	1205	0.34	0
85	F	28	2.2	2	2.6	6.8	8.3	0.82	277	247	323	847	1031	0.82	7.5
86	M	52	1.8	2.4	3.2	7.4	11.3	0.65	218	301	393	912	1395	0.65	3
87	M	29	1.8	2.1	2.6	6.5	9.2	0.71	221	257	317	795	1139	0.7	3
88	F	36	1.8	0	0	1.8	7.9	0.23	221	0	0	221	973	0.23	
89	M	45	1.8	2.5	2.1	6.4	9.2	0.7	221	307	263	791	1139	0.69	3
90	M	49	1.8	1.5	2.3	5.6	9.2	0.61	221	187	283	691	1139	0.61	0
91	F	19	1.4	0	0	1.4	8.7	0.16	177	0	0	177	1083	0.16	
92	F	47	1	1.5	2	4.5	9.2	0.49	129	189	245	563	1143	0.49	0
93	F	52	1	1.8	0	2.8	8.8	0.32	129	225	0	354	1093	0.32	0
94	M	40	1.4	2.3	2.1	5.8	10.3	0.56	177	279	257	713	1271	0.56	0
95	M	59	1.8	1.8	1.7	5.3	9.2	0.58	221	227	207	655	1139	0.58	0
96	M	34	1.4	0	0	1.4	9.2	0.15	177	0	0	177	1139	0.16	
97	M	37	1.8	0	0	1.8	7.4	0.24	221	0	0	221	919	0.24	
98	M	30	1.8	2	1.9	5.7	8.8	0.65	221	243	232	696	1093	0.64	0
99	F	31	1.8	1.4	2.4	5.6	10.2	0.55	221	173	303	697	1267	0.55	0
100	M	37	1.8	2.3	1.3	5.4	10.7	0.5	221	291	155	667	1329	0.5	0
101	M	37	1.4	1.7	1	4.1	8.3	0.49	177	205	127	509	1023	0.5	0
102	M	26	1.8	2.2	2.1	6.1	9.7	0.63	221	267	255	743	1205	0.62	3
103	M	32	1.8	2.8	1.9	6.5	10.2	0.64	221	349	230	800	1267	0.63	0
104	M	56	1.4	0	0	1.4	9.7	0.14	177	0	0	177	1197	0.15	
105	M	21	1.4	0	0	1.4	7.8	0.18	177	0	0	177	969	0.18	
106	M	33	1.4	1.1	1.4	3.9	8.8	0.44	177	141	171	489	1093	0.45	0
107	M	47	1.8	0	1	2.8	7.8	0.36	221	0	125	346	969	0.36	0
108	F	28	1.8	1.2	0.8	3.8	7	0.54	221	143	103	467	869	0.54	0
109	M	39	1.4	1.1	1.3	3.8	9.7	0.39	177	139	163	479	1197	0.4	2
110	F	56	1.4	0	0	1.4	6.5	0.22	177	0	0	177	807	0.22	
111	M	19	1.5	1.5	1.5	4.5	9.2	0.49	183	187	189	559	1139	0.49	2
112	M	29	1.4	0	0	1.4	8.3	0.17	177	0	0	177	1031	0.17	
113	F	20	1	0.4	0.5	1.9	7.8	0.24	129	49	62	240	969	0.25	0
114	M	20	1.44	0	0	1.44	8.3	0.17	177	0	0	177	1029	0.17	
115	F	35	1.8	1.8	1.4	5	11.3	0.44	221	223	173	617	1395	0.44	0
116	M	36	2.2	1	1	4.2	12.4	0.34	277	125	127	529	1535	0.34	
117	M	29	1.44	1.9	0	3.34	12.44	0.27	177	231	0	408	1531	0.27	0
118	M	37	1.8	0	0	1.8	9.2	0.2	221	0	0	221	1139	0.19	
119	M	21	1.4	2.3	2.1	5.8	8.3	0.7	177	285	265	727	1029	0.71	3
120	M	21	2.8	3.8	4.3	10.9	13.5	0.81	349	467	535	1351	1667	0.81	7

TABLE 2: Summary Statistics for All Variables

	Age	Area_Cord	Area_Right	Area_Left	Area_Sum	Area_For	Rat_Area	Ton_LV
Sample Size	120	120	120	120	120	120	120	73
Minimum	18	1	0	0	1	4.3	0.12	0
Maximum	66	2.8	3.8	4.3	10.9	13.5	0.85	12.5
Median	36	1.5	0.95	0.7	3.2	8.8	0.37	0
Mean	37.46	1.61	1.02	0.94	3.58	8.68	0.4	1.35
Std Dev.	10.84	0.31	1.05	1.04	2.15	1.66	0.21	2.21

TABLE 3: Contingency Table - TAM by Sex

	Sex		
TAM	Female	Male	Total TAM
" "	20	26	46
"*"	40	34	74
Total by Sex	60	60	120

Chi-squared statistic = 1.27
Critical value (df = 1, 95%) = 3.841

TABLE 4: Contingency Table - FMI by Sex

	Sex		
FMI	Female	Male	Total by Index
0.10 - 0.19	11	14	25
0.20 - 0.29	11	13	24
0.30 - 0.39	8	7	15
0.40 - 0.49	6	5	11
0.50 - 0.59	10	10	20
0.60 - 0.69	5	5	10
0.70 - 0.79	6	5	11
0.80 - 0.89	3	1	4
Total by Sex	60	60	120

Chi-squared statistic = 10
Critical value (df = 7, 95%) = 14.067

TABLE 5: Test for Difference in mean FMI by Sex

	Sex		Difference
	Female	Male	
Mean	0.423	0.381	0.042
Std Dev	0.214	0.197	0.205
Sample Size	60	60	120

t-Statistic = 1.124
Critical Value = 1.98

TABLE 6: Test for Difference in Mean Age by TAM

	TAM		Difference
	" "	"*"	
Mean	38.230	36.970	1.260
Std Dev	11.597	10.386	11.008
Sample Size	60	60	120

t-Statistic = 0.627
Critical Value = 1.98

TABLE 7: Test if Age is a significant discriminator of the FMI

LS // Dependent Variable is FMI

SMPL range: 1 - 120
Number of observations: 120

VARIABLE	COEFFICIENT	STD. ERROR	T-STAT.	2-TAIL SIG.
C	0.4500855	0.0679698	6.6218448	0.000
AGE	-0.0012815	0.0017436	-0.7349450	0.464

R-squared	0.004557	Mean of dependent var	0.402083
Adjusted R-squared	-0.003879	S.D. of dependent var	0.205704
S.E. of regression	0.206103	Sum of squared resid	5.012435
Durbin-Watson stat	1.895080	F-statistic	0.540144
Log likelihood	20.26158	F-critical	2.75

Conclusion: Accept H_0 that Age is not a significant discriminator.

TABLE 8: Test for Difference in FMI by TAM

	TAM		Difference
FMI	" "	"*"	
Mean	0.202	0.526	-0.324
Std Dev	0.050	0.163	0.132
Sample Size	46	74	120

t-Statistic = -16.58
Critical Value = -1.98

TABLE 9: Correlation Table for TAM "*" (n=73)

	AR_FOR	RAT_AR	TON_LV
AR_FOR	1	0.069	0.16
RAT_AR	0.069	1	*0.672*
TON_LV	0.16	*0.672*	1

TABLE 10: Correlations where TON_LV > 0 (n=32)

	RAT_AR	TON_LV	LN(TON_LV)
RAT_AR	1	0.67	*0.74*
TON_LV	0.67	1	0.89
LN(TON_LV)	*0.74*	0.89	1

TABLE 11: Sex comparison by technique

	Tonsil Level >= 5	Foramen Magnum Index >= 0.75
Female	4	7
Male	1	1

TABLE 12: Test if theTonsillor Level is an indicator of the FMI

LS // Dependent Variable is FMI
SMPL range: 1 - 32
Number of observations: 32

VARIABLE	COEFFICIENT	STD. ERROR	T-STAT.	2-TAIL SIG.
C	0.5140474	0.0264655	19.423312	0.000
LOG_TLV	0.1460301	0.0244749	5.9665348	0.000

R-squared	0.542680	Mean of dependent var	0.635312
Adjusted R-squared	0.527436	S.D. of dependent var	0.139492
S.E. of regression	0.095891	Sum of squared resid	0.275854
Durbin-Watson stat	1.786092	F-statistic	35.59954
Log likelihood	30.65187	F-critical	2.87

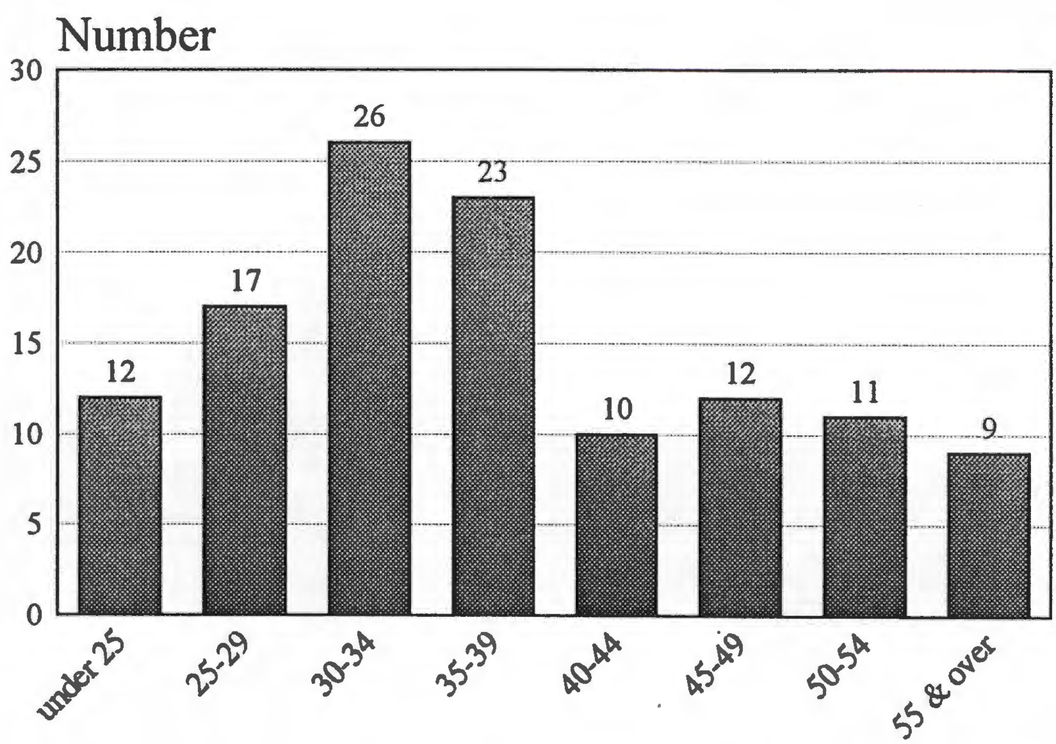
Conclusion: Reject the hypothesis that the log of the tonsillor level is not a significant indicator of the FMI.

APPENDIX B

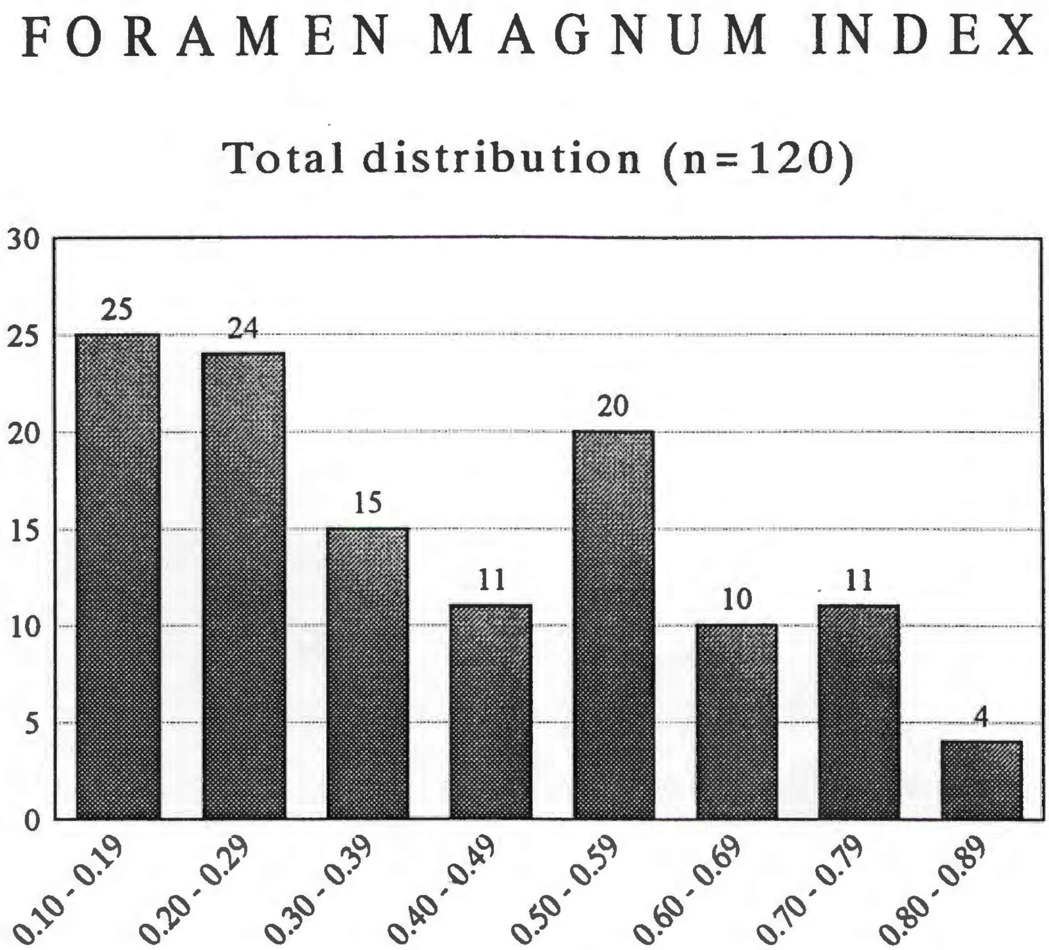
GRAPHS

A G E P R O F I L E

Total Sample

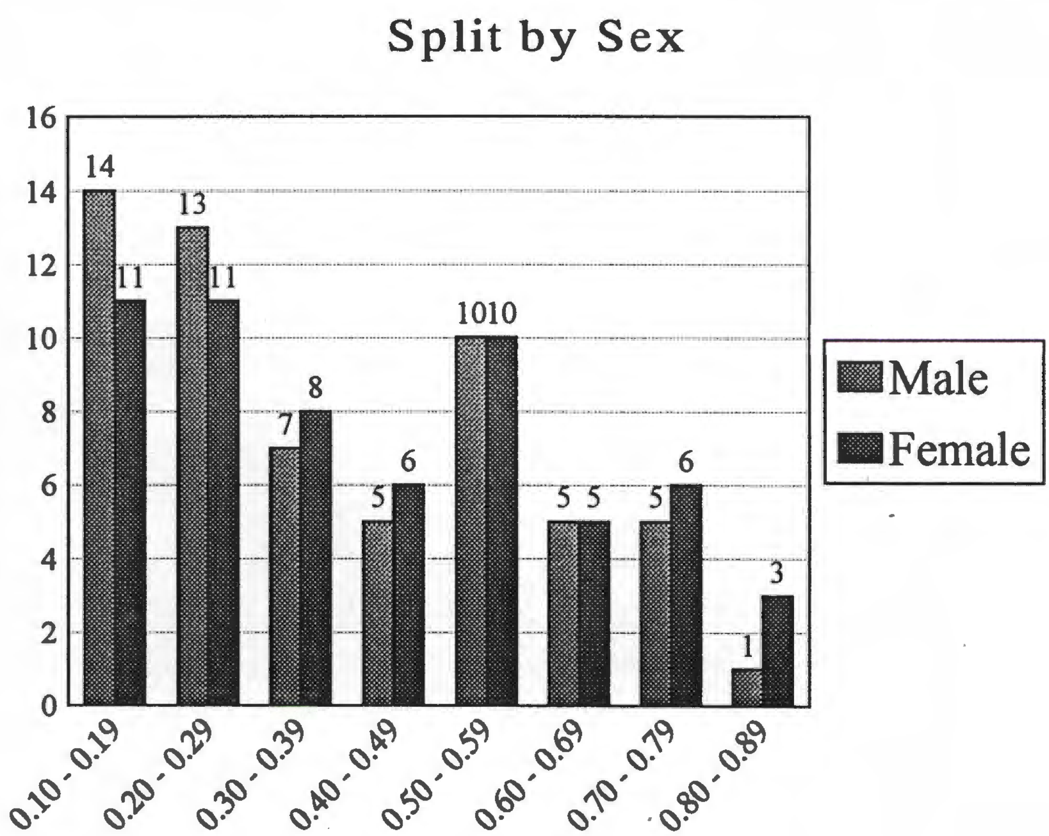


Graph 1: Age bands



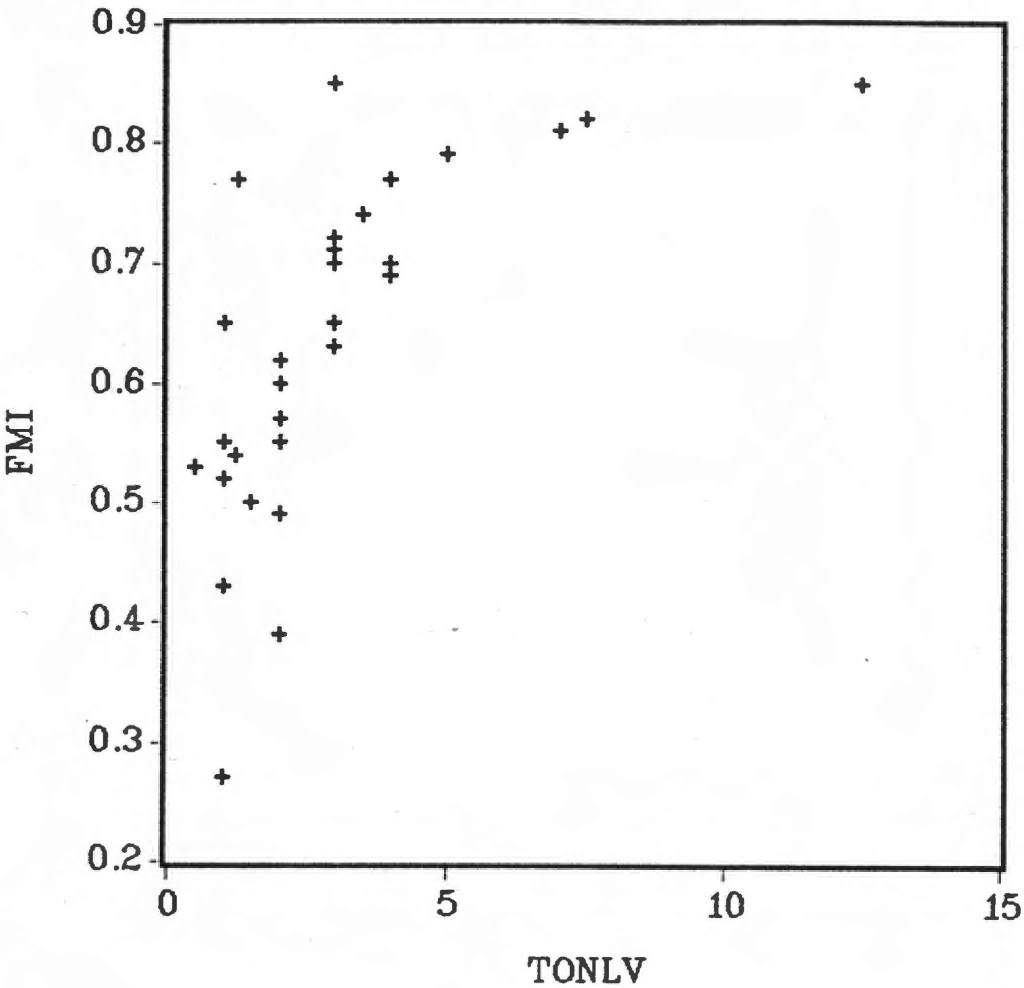
Graph 2: FMI Intervals

FORAMEN MAGNUM INDEX



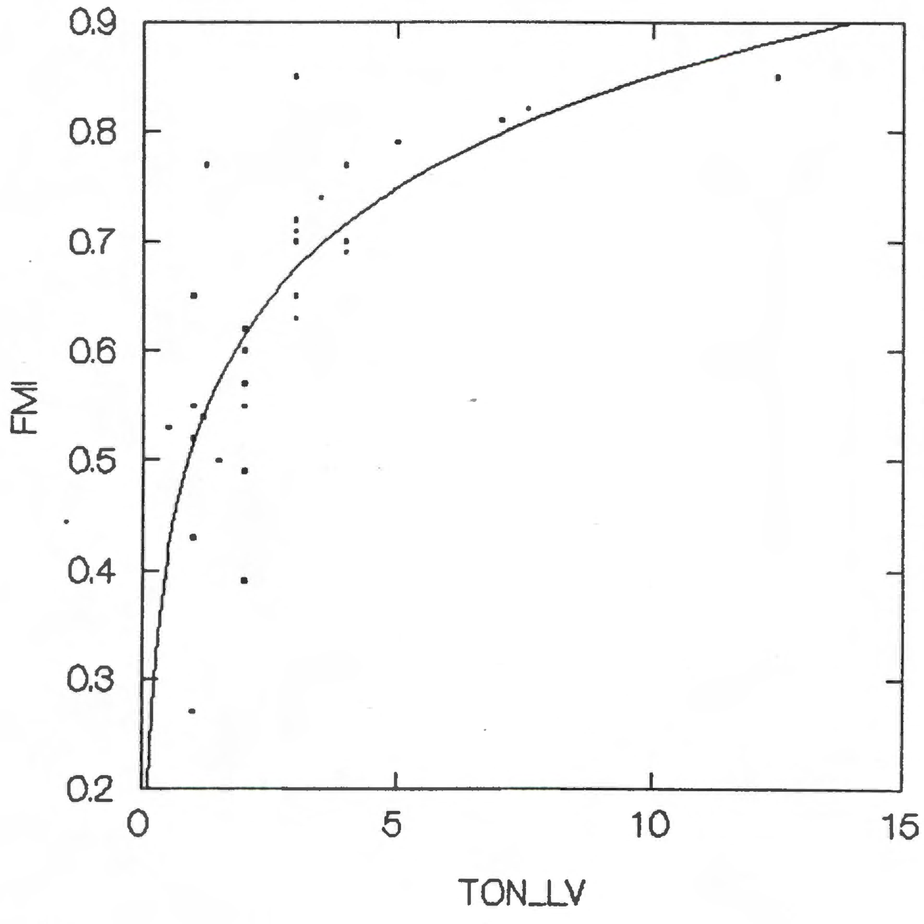
Graph 3: FMI Intervals

Relationship between FMI & TonLV

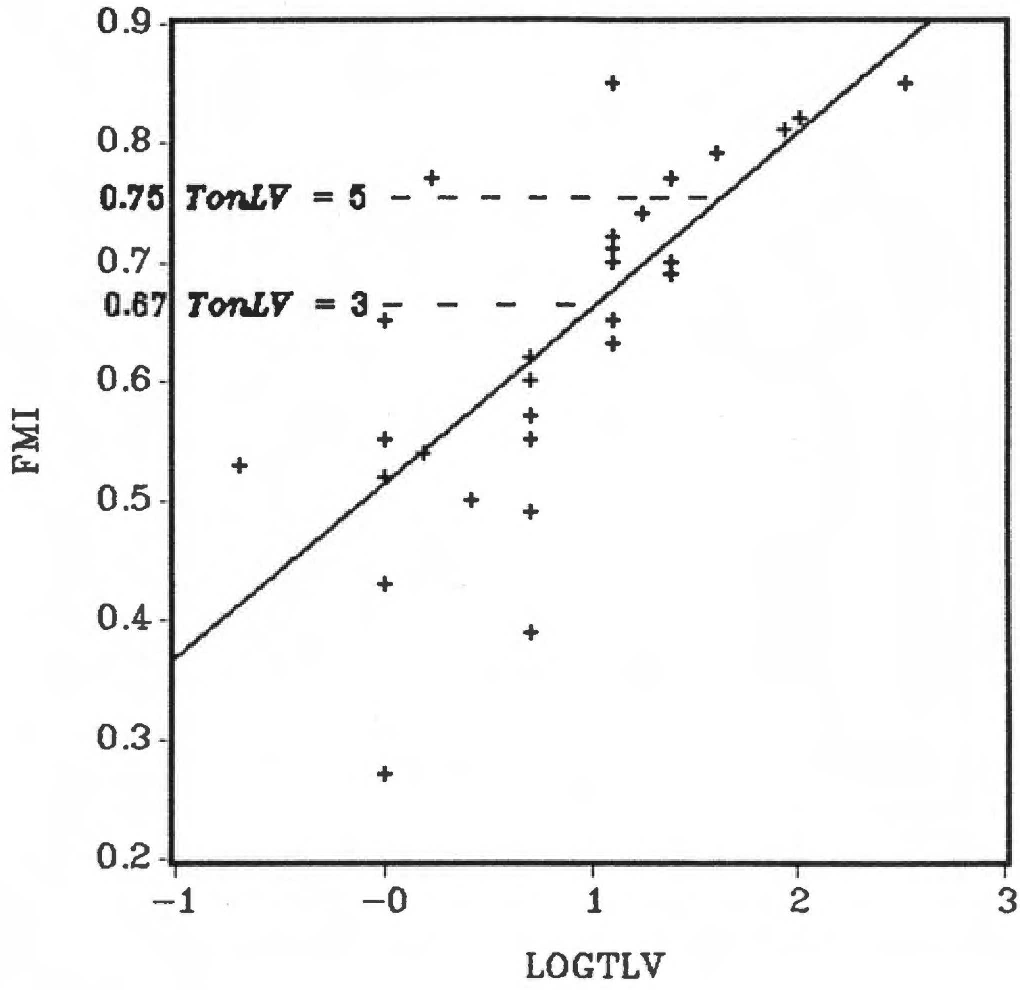


GRAPH 4

GRAPH 5

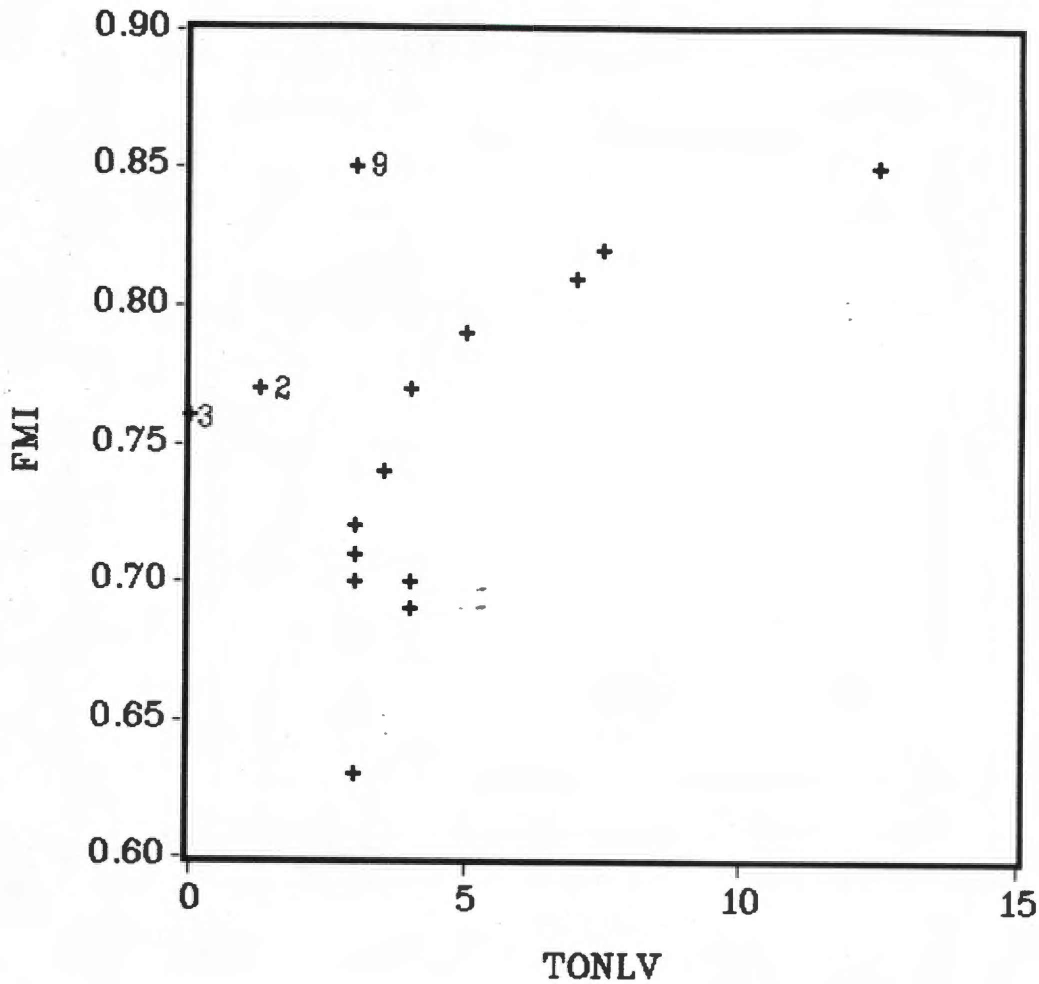


Relationship between FMI & Tonsil Level



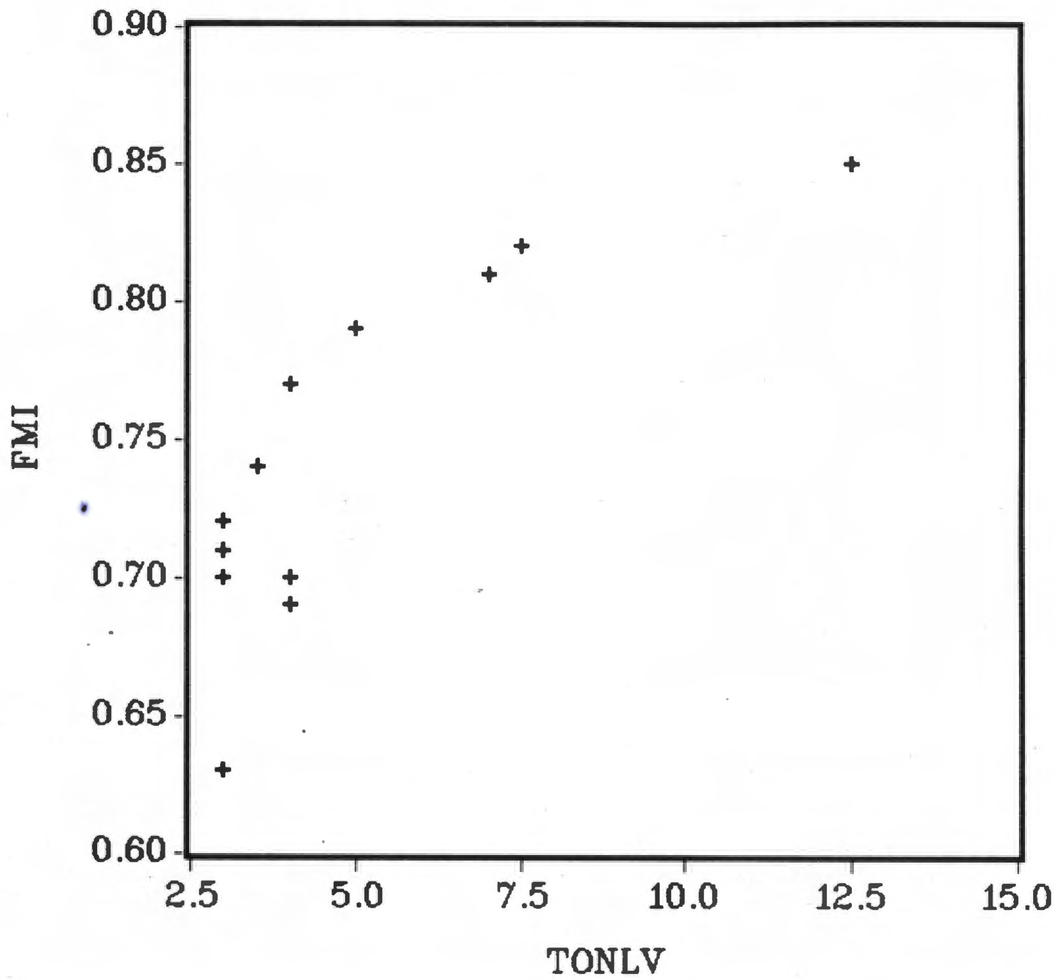
GRAPH 6

Abnormal Group (*n*=17)



GRAPH 7

Abnormal Group without outliers



GRAPH 8